HYDRAULIC CEMENT.

ITS PROPERTIES, TESTING, AND USE.

BY

FREDERICK P. SPALDING,

Professor of Civil Engineering, University of Missouri;
Member of the American Society of Civil Engineers.

SECOND EDITION.

FIRST THOUSAND.

NEW YORK:
JOHN WILEY & SONS
LONDON: CHAPMAN & HALL, LIMITED.
1906.

ROBERT DRUMMOND, PRINTER, NEW YORK

PREFACE TO FIRST EDITION.

THE following pages contain the results of a careful study of the nature and properties of hydraulic cement, and the various methods which have been proposed, or are in use, for testing cement.

The subject is not so simple as it might seem to the casual observer, but abounds in contradictions in the results of experiments and conflicts of opinion between authorities, which at times are quite bewildering.

The views of the author, as derived from his own observation of the behavior of cement in use or in the laboratory, have been stated without reserve, and free use has been made of the results of available European investigations. The recommendations of the recent commissions appointed in Europe for the study of the methods of testing materials are fully given in so far as they relate to cement.

The various tests applied for determining the quality of cement are discussed, and an effort is made to point out the limitations within which they may be accepted as reliable indications of value.

A chapter is given upon the use of cement in mortar

and concrete, and a number of sample specifications are appended for the purpose of showing the present practice of leading American engineers.

F. P. S.

ITHACA, N. Y., March, 1897.

PREFACE TO SECOND EDITION.

In this edition a general revision of the book has been made with the purpose of including the results of the most recent investigations concerning the composition and properties of cement, and of presenting the latest standard methods of cement testing.

The articles relating to the constitution of cement have been practically rewritten, while those upon the testing of cement have been thoroughly revised.

The specifications appended have been changed in order to show examples of existing practice.

F. P. S.

Columbia, Mo., October, 1905.

CONTENTS.

CHAPTER I.

HYDRAULIC LIME.

CHAPTER II.

CLASSIFICATION AND CONSTITUTION OF CEMENT.

CHAPTER III.

THE SETTING AND HARDENING OF CEMENT.

CHAPTER IV.

THE SOUNDNESS OF CEMENT.

CHAPTER V.

METHODS OF TESTING CEMENT.

CHAPTER VI.

TESTS FOR THE STRENGTH OF MORTAR.

CHAPTER VII.

TESTS FOR SOUNDNESS.

CHAPTER VIII.

SPECIAL TESTS.

CHAPTER IX.

CEMENT MORTAR AND CONCRETE.

APPENDIX.

SPECIFICATIONS FOR THE RECEPTION OF CEMENT.

HYDRAULIC CEMENT.

CHAPTER I.

HYDRAULIC LIME.

ART. 1. DEFINITION.

LIME is the name commonly applied to the product obtained by the calcination of limestone. The limestones employed differ greatly in composition, and the properties of the limes obtained from them vary with the nature and proportions of the substances combined in them.

When the limestone is composed of nearly pure carbonate of lime, the clinker resulting from the burning, known as *quicklime*, possesses the property of breaking up, or *slaking*, upon being treated with a sufficient quantity of water. The slaking of lime is due to its rapid hydration when in contact with water, and the process is accompanied by a considerable increase in the volume of the mass of lime and by a rise in temperature. If the quantity of water be only sufficient to cause the hydration of the lime, the quicklime is reduced to a dry powder; while if the water be in excess it becomes a paste.

The slaked lime thus formed possesses the further

property, when mixed to a paste with water and allowed to stand in the air, of hardening and firmly adhering to any surface with which it may be in contact. This hardening of common limes will take place only when exposed to the air and allowed to become dry.

When lime is nearly pure and its activity is very great it is known as *fat lime.*

If the lime have mixed or in combination with it considerable percentages of impurities of an inert character, which act as an adulteration to lessen the activity of the lime, causing a partial loss of the property of slaking and also diminishing its power of hardening, it is known as *meagre lime.*

When the impurities in the lime are composed mainly of silica and alumina, they may, while lessening or destroying its property of slaking, impart to it the power of hardening under water and of *setting* without reference to the presence of air.

When the proportions of the hydraulic ingredients are such that the material possesses the property of hardening in water, without having entirely lost that of slaking, the material is known as *hydraulic lime.*

If the acquirement of hydraulic properties has been accompanied by an entire loss of the property of slaking, the product is *hydraulic cement.*

Hydraulic limes and cements may be made either by burning limestones containing the proper proportions of hydraulic ingredients, in which case they are known as *natural* limes or cements, or by the admixture of material containing such ingredients to the limestone before burning, or to the lime afterward, in which case they are known as *artificial* limes or cements.

The materials used in the manufacture of lime and cement vary widely in different localities, and the resulting products differ greatly in their properties, being affected both by the composition of the raw materials and by the manipulation given them during the process of manufacture. Because of this variation in the character of the material, it is extremely difficult to formulate any general laws governing its properties, or to devise any system of testing which shall give an accurate determination of value.

Hydraulic limes are used quite extensively in Europe, but are not made to any extent in this country. The American cement industry is, however, a very important one. Natural cements are manufactured in immense quantities, and the production of Portland cement is rapidly growing to large proportions, although considerable high-grade foreign cement is still imported.

ART. 2. CHEMICAL INGREDIENTS.

The most important ingredients of hydraulic limestones, in addition to the carbonate of lime, are usually alumina, silica, oxide of iron, and magnesia. They commonly contain also small quantities of sulphuric acid, phosphoric acid, oxide of manganese, potash, soda, bituminous or carbonaceous matter, organic substances, and water. The lime after burning may also contain small particles of cinders from the combustibles employed.

The volatile substances are without effect upon the lime because they disappear in burning. A small percentage of carbonic acid and water which escapes being

driven off in the burning or is afterward absorbed from the air will appear in the lime. If this quantity of carbonic acid be large, it indicates either that the burning has been incomplete or that the lime has become carbonated by subsequent exposure. The energy of the lime is thus diminished, the portion of lime in combination with the carbonic acid being rendered inert.

Silica is undoubtedly the most important element in rendering lime hydraulic and is always present. When in the form of silicious sand not attacked by acids it is unaffected by the burning and remains as inert material in the product. It is only that portion of the silica which is present in a condition to be reduced in the burning and combine with the lime which is of value in imparting hydraulic properties to the lime.

Alumina is an important element in hydraulic lime, although not, as seems to be the case with silica, an essential to its hydraulicity. Vicat found that alumina without silica would not render lime hydraulic. When, however, it is combined with silica it becomes one of the active elements in the setting and hardening of hydraulic limes and cements, provided it be not present in too large proportions. When in excess of about one part alumina to two parts silica, it is claimed that the surplus remains inert in the lime and detracts from its energy. This, however, very rarely happens in practice.

Oxide of Iron is commonly thought to be without influence upon the hydraulicity of lime, although there is some question concerning it. Like alumina, it confers no hydraulic properties when alone, and it is probably always inert.

Magnesia seems to act quite differently as the con-

ditions under which it is present vary, and its real action in most cases is in considerable doubt. Vicat made hydraulic limes by burning carbonate of magnesia with fat lime, thus showing that the magnesia alone might impart hydraulic properties to the lime. It has also been shown by Mr. H. St. Claire Deville that the oxide of magnesium by itself is sometimes an hydraulic material and sets under water. Other experiments have seemed to indicate that magnesia might act like alumina, and replace that element in forming an hydraulic material with silica and lime. These results may possibly all be due to the hydraulic properties of the magnesium oxide and independent of any action of the magnesia upon the lime.

The silicates and aluminates of magnesia also have the property of hardening under water like the similar salts of lime, and in some cements a portion of the lime which would otherwise be required seems to be replaced by magnesia. The action in these instances is not definitely known, and there is a difference of opinion amongst authorities concerning it, some thinking that the magnesia acts like lime, others that it is inert and does not contribute to the energy of the material. In view of the activity of the magnesian salts when alone, it seems reasonable to suppose that they have a similar effect in the magnesian cements.

The activity of magnesia in hydraulic material depends largely upon the temperature at which it is burned, and in the experiments which have demonstrated its hydraulic properties it has been found that too high temperature destroys these properties. This possibly accounts for many of the contradictory results obtained

by different investigators with these salts. This also is true in a less degree with the lime salts, which may sometimes be rendered inert by too high temperature.

Sulphuric Acid occurs in some limestones as sulphate of lime, and sulphur also sometimes occurs as a sulphide, usually of iron. During the burning the sulphide may become transformed into sulphate, and either or both forms may result in the final product. Experience seems to indicate that the sulphate is, in general, a deleterious substance, likely to affect the durability of mortar made from lime in which it occurs. The sulphide, however, is supposed to increase the hydraulic properties of the material, although its action is doubtful. In Europe it is common to limit the percentage of sulphur or sulphuric acid which may be present in the lime.

Phosphoric Acid occurs in very small quantities in material of this character, and is thought to have no action other than that of combining with a small quantity of lime, which is thus rendered inert.

Oxide of Manganese is comparatively unimportant, as the quantity present is always too small to have any considerable effect upon the properties of the lime. It has been supposed by some authorities to have strong hydraulic properties.

The *Alkalies* contained in the limestone act as a flux during the burning, causing the chemical reactions to take place more readily and completely. The small amount which ordinarily occurs in lime and cement is unimportant in its effect, the alkali being gradually dissolved out of the mortar.

Art. 3. Hydraulic Index.

The hydraulic activity of a lime or cement, that is, its ability to harden under water, depends primarily upon the relative proportions of the hydraulic ingredients and of lime. Silica and alumina are considered to be the effective hydraulic ingredients, and it is common to designate the ratio of the sum of the weights of silica and alumina to that of lime in the material its *hydraulic index*.

The hydraulic index gives, therefore, within certain limits, a measure of the hydraulicity of the various classes of limes. It is to be remembered, however, that there are other factors to be considered in judging of the action of a lime than this simple proportion. The other ingredients may by their combinations withdraw portions of the active elements so as to modify the effective ratio between them, while the activity of the lime depends largely upon the state of combination in which the active elements exist. This is not shown by analysis, and may be greatly modified by the manipulation given the material during manufacture.

Art. 4. Classification of Limes.

Limes may be classified according to their hydrauiic indices, or according to the rate of hardening under water.

Limes with hydraulic index less than 10/100 possess little if any hydraulic properties, and are known as *common limes*, which may be either *fat limes* or *meagre*

limes according to the proportion of inert material contained by them.

When the hydraulic index is between 10/100 and 20/100 the lime is known as *feebly hydraulic* and may require from 12 to 20 days to harden under water. Hydraulic lime proper includes that of index varying from about 20/100 to 40/100. These may harden in 2 to 8 or 10 days, the more rapid ones being sometimes classed as *eminently hydraulic.*

When the hydraulic index is between about 40/100 and 60/100 the lime is of the class known as *limiting lime.* These limes have not the characteristics of hydraulic lime, but form the boundary between the limes proper and the cements, losing the property of slaking, and as a general thing not possessing a sufficient quantity of the hydraulic ingredients to make a safe natural cement. When burned at a low temperature it may give hydraulic lime of rather poor quality, and when properly treated and burned at a high temperature it makes good Portland cement. From material with an index of 65/100 to $1\frac{20}{100}$ are obtained most of the common *natural cements.* With hydraulic index of $1\frac{20}{100}$ to $3\frac{00}{100}$ the material yielded by burning is known as *meagre cement,* usually a weak material of little value as a cement.

The material of hydraulic index $3\frac{00}{100}$ may be puzzolana, which has the properties of cement, but when mixed with fat lime renders the lime hydraulic.

The above divisions are all more or less arbitrary, and there are no sharp lines between the classes, which merge into and overlap each other. The character of the material is also affected by other factors than the hydraulic index, and classification by this method is by

no means invariable, material of one class frequently behaving like that of another class. It is difficult to determine at exactly what point lime begins to be hydraulic, but when it requires a month or more to harden under water it is usually considered as being non-hydraulic.

In determining the rate of hardening of limes there are so many external circumstances which may affect the result that there is always chance for error, which causes classification by that method to be somewhat uncertain. Variation in temperature has always an important effect upon the rate of hardening.

Art. 5. Common Lime.

Common lime is such as does not possess hydraulic properties. It is divided into fat or rich lime and meagre lime, according to the quantity of impurities of an inert character it may contain. When made into a paste and left in air it slowly hardens. The process of hardening consists in the gradual formation of carbonate of lime through the absorption of carbonic acid from the air, accompanied by the crystallization of the mass of hydrated lime as it gradually dries out. In common lime the final hardening takes place very slowly, working inward from the surface, as it is dependent upon contact of the mortar with the air. When the lime is nearly pure the resulting carbonate is likely to be somewhat soluble, and consequently to be injured by exposure. Nearly all limes, however, contain small percentages of silica and alumina, and these ingredients, even when in quantities too small to render the lime hydraulic, impart

a certain power to set, causing the hardening to take place with greater rapidity and without the same dependence upon contact with air. It also renders the material less soluble and more durable in exposed situations.

Limes containing but a small amount of impurities consist mainly of calcium oxide, which is very caustic and becomes hydrated very rapidly when brought into contact with water. This hydration, or slaking, produces a rise in temperature and an increase in volume which vary in amount according to the purity of the lime, the volume being doubled or tripled for good fat lime.

The common method of slaking consists in covering the quicklime with water, using two or three times the volume of the lime. This method is known as *drowning.* The lime is usually spread out in a layer, perhaps 6 or 8 inches thick, in a mixing-box, the water poured over it and allowed to stand. Sufficient time must be allowed for all of the lumps to be reduced. When the lime contains much foreign matter, the operation frequently requires several days.

Too great a quantity of water is to be avoided, the amount necessary being such as will reduce the lime after slaking to a thick pasty condition. All the water should be added at once, as the addition of water after the hydration is in progress causes a lowering of temperature and checks the slaking. For the same reason, the lime should be covered after adding water, and not stirred or disturbed until the slaking is completed. The covering is commonly effected by spreading a layer of sand over the lime, the sand being afterward used to mix with it in making the mortar.

A second method of slaking is sometimes employed

having for its object the reduction of the slaked lime to powder and known as *slaking by immersion*.

Slaking by immersion is accomplished in two ways. By the first method, the lime is suspended in water in baskets for a brief period to permit the absorption of the necessary water, after which it is removed and covered until the slaking takes place and the lime falls to powder.

By the second method, sprinkling is substituted for immersion proper, the lime being placed in heaps and sprinkled with the necessary quantity of water, then covered with sand and allowed to stand.

The difficulty in using these methods is to get just the right quantity of water to make the slaking complete. Lime so slaked may be barreled and shipped in form of powder.

Spontaneous Slaking is also sometimes resorted to; it consists in exposing the lime to the air until slaking is effected by absorption of moisture.

Lime slaked by immersion swells less than when slaked by drowning and requires less water to form into a paste. Slaked lime, either as powder or paste, may be kept indefinitely if protected from the air.

Lime is commonly sold as quicklime, and should be in lumps and not air-slaked. When it is old and has been exposed to the air, it is likely to have absorbed both moisture and carbonic acid, thus becoming less active, the portion combined with the carbonic acid being inert. A simple test of the quality of quicklime is to immerse a lump for a minute, then place in a dish and observe whether it swells, cracks, and disintegrates with a rise of temperature.

Slaking some days in advance of use is desirable in

order to insure the complete reduction of the lime, and it is quite common to slake lime much longer before it is to be used.

The swelling of lime has been found to be increased by slaking with steam instead of water, and slaking has been found by Candlot to be accelerated by the addition to the water of a small quantity (2% to 6%) of chloride of calcium or chloride of magnesium.

Common lime is ordinarily used in construction as a mortar, mixed with sand. The quantity of lime in the mortar should be just sufficient to fill the voids in the sand, without leaving any part formed entirely of lime. Mortar of rich lime shrinks on hardening, while masses composed entirely of lime on the interior are likely to remain soft, so that an excess of lime may be an element of weakness. If too little lime be used the mortar may be porous and weak. The proportions ordinarily required are between 1 part lime to 2 parts sand, and 1 part lime to 3 parts sand.

Mortar of common lime should not usually be employed in heavy masonry or in damp situations. Where the mass of masonry is large, the lime mortar will become hardened only with great difficulty and after a long time. The penetration of the final induration due to the absorption of carbonic acid is very slow. The observations of M. Vicat showed that carbonization extended only a few millimeters the first year and afterward more slowly. The induration of the lime along the surfaces of contact with a harder material, when used in masonry, is usually more rapid than in the interior of the mass of lime itself, and hence the strength of adhesion to stone or brick is

often greater than that of cohesion between the particles of mortar.

Meagre limes are similar in action to fat limes, but less energetic. They swell feebly in slaking and with slight change in temperature. The mortar hardens like that of fat lime, but cracks less and contracts less. Meagre limes proper, those containing so much inert matter as to materially reduce the energy, are not commonly employed in construction.

Art 6. Hydraulic Lime.

Hydraulic lime is obtained by burning limestone containing silica and alumina in sufficient quantity to impart the ability to harden under water. The hydraulic elements are present in such quantities that they combine with a portion of the lime, forming silicates and aluminates of lime, leaving the remainder as *free lime* in an uncombined state.

When treated with water the free lime is slaked, the action being much less energetic than that of fat lime and varying in intensity with the quantity of hydraulic ingredients.

The quantity of free lime in the material is dependent upon the degree of burning, as well as upon the amount of lime contained by the stone. If the stone be underburned, the combination of the hydraulic elements with the lime is not complete, and more of the lime remains in a free state. For this reason a stone of high hydraulic index may give a lime when underburned, but become unslakable when burned at a high temperature, as in

the case of the limiting limes. The best limes are usually those which can be burned at a high temperature to complete the chemical combinations.

It is necessary that sufficient free lime be present to cause the lime to slake properly, but it is desirable also that the quantity of uncombined lime be as small as possible, as the setting properties are due to the silicates and aluminates, while the hydrated lime remains inert during the initial hardening of the mortar.

According to Professor Le Chatelier, limestone for hydraulic lime should contain but little alumina, as the aluminates are hydrated during the slaking of the lime and become inert, while the silicates are not affected, the heat of the slaking preventing their hydration.

The following is given as an average analysis of the best French hydraulic lime:

Silica	22
Alumina	2
Oxide of iron	1
Lime	63
Magnesia	1.5
Sulphuric acid	0.5
Water	10.0
	100

It is important that the slaking be very thorough, as the presence of unhydrated free lime in the mortar while hardening is an element of danger to the work. Any lime becoming hydrated after the setting of the mortar may, by its swelling, cause distortion and perhaps disintegration of the mortar.

Hydraulic lime is used in the same manner as fat lime, being mixed with sand to a paste. When in the air hydraulic lime acts like common lime, dries, hardens, and slowly absorbs carbonic acid. It contracts and cracks when without sand, but much less than fat lime. In water, or in damp situations, the action of the two are altogether different. The hydraulic lime then hardens more or less rapidly. In running water a small amount of the lime is at first dissolved, but this is soon arrested as the hardening progresses.

Hydraulic lime is commonly slaked at the manufactory and shipped in form of powder. It may be kept, without injury, in this form by covering and protecting from the air.

ART. 7. MANUFACTURE OF HYDRAULIC LIME.

The manufacture of hydraulic lime as commonly carried on in Europe consists, after the quarrying of the rock, of burning, slaking, and bolting the material. As already stated, it is usually slaked at the works and sold in the form of powder.

The varieties of furnaces used in burning are quite numerous, but may be divided into those in which the stone is burned in contact with the fuel, and those in which the fire is outside the chamber in which the burning takes place.

Furnaces of the first class have been more generally employed, and are claimed (Candlot, Ciment et Chaux hydrauliques, p. 7) to be preferable from the point of view of the uniformity of product. Continuous fur-

naces are commonly used. The furnace is filled by placing alternate layers of combustible and limestone. When full it is lighted at the bottom, and as the mass settles, new layers of material are added at the top, while the burned lime is drawn out at the bottom, the furnace being kept in continuous operation. The rapidity of burning is controlled by dampers and the movable cover at the top.

In furnaces of the second class, the flame and gases of combustion are passed through the stone, which is not in direct contact with the fuel.

The regulation of a furnace to secure the proper degree of burning is a matter requiring skill and experience and demanding the close attention of the attendant. The lime must be completely burned, but not overburned. The character of the limestone determines the amount of burning necessary. A lime of low hydraulic index may be burned at a much higher temperature than one of high index. When the limestone is irregular in character it will not burn evenly, but the parts of high index will be vitrified before that of low index is properly burned. The burning is accelerated when the stone is moist, and stone fresh from the quarry is preferred to that which has been exposed until the hygrometric water has been evaporated.

The chemical phenomena of the burning of lime are approximately as follows: The hygrometric water is first driven off. The carbonate of lime is next decomposed. Then the clay is dehydrated and decomposed, and the combination of the silica and alumina with the lime takes place. The temperatures required to effect these changes depend upon the composition. The de-

composition of the carbonate of lime ordinarily occurs at a temperature of 700° C. to 900° C., and the temperature required for burning depends upon the amount of silica and alumina present. When the hydraulic index is low the temperature must be sufficient to effect complete combinations of the lime with the silica and alumina in order to impart hydraulic properties to the product, while if the hydraulic index be high a temperature but little greater than that necessary to decompose the lime may be sufficient, and a higher temperature, which would effect complete combinations of the lime with the silica and alumina, may so greatly reduce the amount of free lime as to destroy the property of slaking,

The *slaking* of hydraulic lime is commonly accomplished by sprinkling, as mentioned in Art. 5. The lime after coming from the furnace is spread in layers 4 to 8 inches deep in the slaking-chambers. It is then sprinkled so that all of the quicklime is well moistened; from 7% to 10% of water is commonly required. When the lime is wet it is thrown into large heaps and left for a sufficient time for the slaking to be completed. The time required varies with the hydraulic index and the degree of burning. Limes of high index may require 15 to 20 days. When the index and degree of burning increase together, the lime soon becomes unslakable.

In slaking, the object is to obtain the complete hydration of the uncombined lime without causing any change in the silicates. To accomplish this the slaking must take place at a high temperature. The heat of slaking volatilizes the surplus moisture and prevents the hydration of the silicates. If the temperature be too low, the lime may partially harden during slaking and the portion

of silicate which is hydrated becomes inert. If the lime be imperfectly slaked, the free lime left in the material may cause injury to the mortar after hardening. Lime so affected will set more quickly than it would if sound, but afterward is likely to swell and crack.

Steam is sometimes used for slaking instead of water and is said by Le Chatelier to act more rapidly upon the lime while producing no effect upon the silicates.

It is claimed that the aluminates are hydrated during the slaking of the lime, being readily acted upon by steam, and hence are undesirable in hydraulic lime.

After the lime has been reduced to powder by slaking it is forced through sieves which permit the passage of all pulverized particles, but hold those of appreciable size, including the underburned rock and the overburned parts which refuse to slake. The lime resulting from the first bolting is known as the *flour of lime.*

ART. 8. GRAPPIERS.

The residue left after the sifting of hydraulic lime is known as *grappiers.*

It differs very much in its composition in various instances, depending upon the limestone used and the manipulation in manufacture. It includes the underburned portions of the limestone and the overburned particles which will not slake. When the burning is thoroughly done and the limestone used regular in composition, the proportion of unburned particles is small. The larger part of the residue is then composed of hard material more rich than the other portions of the lime

in silica and alumina, obtained from the clay which is disseminated through the limestone or formed by the combination of the cinders of combustion with the lime. This is what is properly meant by the term *grappiers*.

Bonnami found in his investigations that the larger part of the grappiers are from the surfaces of the limestone which are in contact with the combustible during the burning, and due to the silica and alumina of the cinders. These cinders are usually quite aluminous.

The grappiers are ground and sifted and either added to the lime or used separately as cement.

The addition of ground grappiers to hydraulic lime has the effect of raising the hydraulicindex of the lime and increasing its activity, and offers a means of controlling to a certain extent the properties of the lime. In this case the mixture between the lime and the grappiers must be very intimate in order to obtain a homogeneous material. It is also very important that the lime in the grappiers be entirely slaked, to prevent the introduction of free lime into the product. To secure this the grappiers after grinding are exposed to the air for a considerable time before using, thus permitting any unslaked particles to become air-slaked.

The following analyses of lime and grappiers from the great works at Teil are given by Prof. Durand-Claye (Chimie appliquée á la'rt de l'ingénieur).

The first column gives the ordinary slaked lime. Merchantable lime has a portion of powdered grappiers added to augment its hydraulic properties. The third column gives an analysis of powdered grappiers, which is sold as a slow-setting cement. The rejected material is a calcareous sand which has puzzolanic properties.

It is employed with cement in making water-pipe, brick, etc.

ANALYSES OF LIME AND GRAPPIERS FROM TEIL.

	Slaked Lime.	Merchantable Lime.	Grappiers.	Rejected Material.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Silica	23.05	23.95	31.85	43.90
Alumina and iron oxide	2.75	3.10	4.25	8.20
Lime	65.75	63.35	55.60	45.25
Magnesia	1.50	1.15	1.20	0.85
Water, etc.	6.95	8.50	7.10	2.60

ART. 9. PUZZOLANA.

The term puzzolana is commonly applied to a class of materials which, when made into a mortar with fat lime or feebly hydraulic lime, impart to the lime hydraulic properties and cause the mortar to set under water.

Puzzolana (or pozzuolana) proper is a material of volcanic origin, deriving its name from Pozzuoli, a city of Italy near the foot of Mount Vesuvius, where its properties were first discovered. It was extensively used by the Romans in their hydraulic constructions, being pulverized and mixed with slaked lime and a small amount of sand for the formation of hydraulic mortar.

The puzzolana is a silicate of alumina in which the silica exists in a state easily attacked by caustic alkalies, and hence readily combines with the lime in the mortar.

The class of puzzolanas also includes several other materials of somewhat similar character.

Trass is the name given to a volcanic material found in Germany and Holland, much resembling puzzolana and used in the same manner.

Arenes is a sand found in France and applied to the same purpose. It is quartzose in character and mixed with clay in considerable proportions—from 1/4 to 3/4 of the total volume. It may be made into a paste with water, which will harden on drying out, and is sometimes used for common mortar without lime.

Psammites is a sandstone consisting of grains of quartz, schist, feldspar, and mica, agglutinized with a variable cement. It is slaty in character and may be worked into a paste with water.

Puzzolana may be made artificially by burning clay, and natural ones may frequently be improved by burning, which has the effect of dehydrating the silicate of alumina of which they are mainly composed and leaving it in condition to combine readily with the lime.

Berthier gives the following analyses of average samples of puzzolanas:

	Trass.	Puzzolana.
Silica	0.570	0.445
Alumina	0.120	0.150
Lime	0.026	0.088
Magnesia	0.010	0.047
Iron oxide	0.050	0.123
Potash	0.070	0.014
Soda	0.010	0.040
Water, etc.	0.444	0.096

CHAPTER II.

CLASSIFICATION AND CONSTITUTION OF CEMENT.

ART. 10. CLASSIFICATION OF CEMENT.

HYDRAULIC cements may be classified, according to the method of manufacture, under five general headings: Portland cements, natural cements, slag cements, mixed cements, and grappiers cements.

The term *Portland Cement* is commonly used to designate hydraulic cement formed by burning to the point of vitrifaction a mixture of limestone and clay in proper proportions and reducing the resulting mass to powder by grinding. The cement so classified is of lower hydraulic index than the other cements, and is consequently burned at a higher temperature. Portland cement is usually made artificially by a mixture of limestone and clay or of nearly pure limestone with stone of high index, and in all cases the material must be very uniformly incorporated into the mixture. The high temperature employed in burning and the necessity of reducing the raw material, whether natural rock or artificial mixture, to powder before burning, for the purpose of homogenizing it, may be considered the distinctive characteristics of this class.

The conference for the unification of methods for

testing materials at Munich * propose the following additional definition of Portland cements: "They contain a minimum of 1.7 parts of lime per unit of hydraulic substances. The addition of 2% by weight of foreign matter may be tolerated in the manufacture of Portland cement, with the view of augmenting certain important qualities, without the necessity of changing the name."

Natural Cements are those which are made by burning limestones less rich in lime than those giving hydraulic limes or Portland cement. These are burned like the hydraulic limes without pulverization of the raw material, and require a much lower temperature in burning than does Portland cement.

This class includes a number of subclasses varying widely in composition and value. In Europe they are commonly divided into quick-setting natural cements, frequently called *Roman Cement*, and semi-slow-setting cements, known sometimes as natural Portland cement. In the United States there is much greater variety in the materials coming within this classification and much confusion in their nomenclature. They are most commonly designated by a name derived from the locality in which they are obtained, and this seems the most feasible and satisfactory method. Thus, Rosendale cements are those from the region of the lower Hudson, Lehigh cements are from Southeastern Pennsylvania, Louisville cements from the Ohio valley, Potomac and James River cements from the corresponding valleys, while Utica, Akron, and Milwaukee are names indicating the location of manufactories of particular brands.

* Mémoires de la Société des Ingénieurs Civils, 1891, vol. 1, p. 112.

The term *American Cement* has sometimes been applied to include all natural cements made in the United States. This, however, often leads to confusion because of the fact that other than natural cements are now made quite extensively in this country, and the term *American Portland Cement* is also in common use.

The term *Rosendale Cement* has frequently been given a general meaning and used as synonymous with natural and American to include all natural cements. It is, however, more properly restricted to the cements of the district in which it was first applied, and there seems to be no good reason for extending it to include other and totally different material.

Slag Cement, or, as a more general term, *Puzzolana Cement*, is the product obtained by an intimate mixture of slaked lime with finely pulverized puzzolanic material, commonly blast-furnace slag. In this material the hydraulic ingredients are not burned with the lime, but are present in the cement in a mechanical mixture only.

Grappiers Cements are obtained by grinding the particles which are not pulverized in slaking hydraulic lime.

Mixed Cement is the name given in Europe to an extremely variable class of products obtained by mixing different grades of cement together, or by mixing cement with other material for the purpose of imparting desired properties.

ART. 11. MANUFACTURE OF CEMENT.

The manufacture of hydraulic cement as commonly practised consists of four operations, viz., the preparation of the raw material, the burning, the cooling, and the grinding.

The methods of preparing the raw material differ according to the nature of the material and the method to be used in burning. For natural cements it is usually only necessary to select the proper portions of the rock and break it into fragments of suitable size for introduction into the furnace. The production of good cement requires the use of homogeneous material, and care must be used to prevent the introduction of variable rock into a single burning.

The methods of preparing the raw materials for the manufacture of Portland cement depend upon the character of the materials and the method of burning to be employed. Several classes of materials are used for this purpose. A hard limestone or chalk, consisting of nearly pure carbonate of lime mixed with clay or shale to furnish the hydraulic ingredients, is frequently employed. In the Lehigh district in Pennsylvania, cement rock, consisting of a limestone containing silica and alumina in sufficient proportions to make a natural cement when burned alone, is mixed with a nearly pure limestone to obtain the Portland-cement mixture. In the Michigan district, marl and clay excavated in a soft and wet condition are used. In a few instances limestone is mixed with blast-furnace slag for the production of Portland cement. This is quite distinct from the

manufacture of slag cement (so called) in which the materials are not burned together.

These materials are first to be reduced to a finely divided state and incorporated into an intimate mixture. This is accomplished either by the wet or dry method, the details of the method varying in the different mills.

In general where the dry method is employed it is necessary to pass the material through dryers before it goes to the grinders, although there are a few instances in which this is not done. These dryers are usually cylinders about 5 feet in diameter and 40 feet long set with axis nearly horizontal, the material previously crushed to small fragments being fed into the upper end and dropping out at the lower end. The materials are then mixed in proper proportions and ground together to very fine powder, when it is ready to go to the kiln if a rotary kiln is to be used or to be made into bricks if a stationary kiln is to be employed. In some instances the above method is modified by grinding the materials separately and afterward putting them through a mixer. In other instances the proportioning is done before crushing, and the materials pass through all the operations together. Where soft materials are being used crushing and grinding may be unnecessary for some of the materials which may be passed directly from the dryers to some sort of incorporator which mixes them thoroughly together.

The wet method is usually applied to materials found in soft and wet condition. The general method is similar to the dry one excepting that the grinding and mixing are done with the materials in a wet condition, resulting in a more or less soft slurry instead of a dry powder.

In preparing the materials for Portland cement very

great care must be exercised in securing the exact proportioning of the ingredients and their thorough incorporation into the mixture. Careful analyses must frequently be made and proportions determined to give proper composition to the cement mixture. Very fine grinding is usually necessary in order that the mixture may be very intimate.

Natural cement is commonly burned in continuous vertical kilns in which the fuel and cement rock are fed together or in alternate layers at the top and the clinker is drawn out at the bottom as the burning proceeds.

For Portland cement rotary kilns are most commonly used in the United States. These kilns have rapidly come into use during the past few years owing to the decreased labor cost of handling the materials, although not so economical of fuel as some of the stationary types of kiln. These kilns are usually cylindrical in shape and set with axis at an angle of about 5° with the horizontal. They vary from about 60 to 110 feet in length and are usually 5 or 6 feet in diameter. In a few instances they are made larger at the lower than the upper end, and the tendency seems to be in the direction of increasing the length. In the use of the kiln a jet of fuel is introduced at the axis of the kiln at the lower end, producing a white heat at that point, and a heat of varying intensity throughout the length of the kiln, the fumes escaping into a stack at the upper end. The materials are introduced in a continuous stream at the upper end and after being carried through the kiln by its rotation drop out as clinker at the lower end.

There are several types of stationary kilns in use. The vertical intermittent kiln is similar to the old form

of lime-kiln, and is used by charging it with a definite charge of the cement material in the form of bricks and fuel in layers. It is then fired, and when burning is complete, allowed to cool, after which the clinker is removed.

The continuous kilns in use are of two general types: the *ring or Hoffman kiln* and the *shaft kiln.*

The Hoffman continuous kiln is a series of chambers arranged in a circle around a central stack, one chamber being fired at a time and the products of combustion passing through the chambers containing unburned material, the firing progressing from chamber to chamber continuously around the kiln.

The Aalborg kiln is a shaft kiln in which a preheating chamber is placed at the top, into which the material is fed in the form of bricks and through which the products of combustion pass; below, the kiln narrows into a furnace in which the burning is done, and into which the fuel is fed, and at the bottom is a cooling-chamber from which the clinker is withdrawn.

The Dietzsch kiln is similar to the Aalborg in principle, but has a horizontal offset or gallery between the fire chamber and the preheating chamber.

The degree of burning required, as already indicated, varies with the character of the material used, and must be very carefully regulated. The heat required is greater as the hydraulic index becomes less and each grade of material has a certain range of temperature within which it should be burned, below which it will be underburned and above which it will be overburned. The time required for burning also depends upon the temperature used, longer time being necessary at lower temperatures.

In underburned cement the chemical changes are

incomplete; a part of the lime may be left as caustic lime uncombined with the clay. This is shown by its light weight. In the burning, as the dehydration of the materials and the decomposition of the carbonate of lime is first effected, the limestone loses in weight without loss of volume, and thus suffers a loss in apparent density. As the subsequent combination of the lime with the clay occurs, a contraction in volume takes place and the density becomes greater.

In stationary kilns the clinker is cooled in the cooling-chambers of the kiln and must be removed by hand. From rotary kilns the clinker drops at a high temperature and must be cooled before passing to the grinders. For this purpose two principal methods are employed. In the vertical tower cooler the clinker after being sprayed with water is elevated to the top of the tower and allowed to slide down through the tower upon a set of shields, upon which it is exposed to a current of air. In the rotary cooler the hot clinker passes from the kiln to a cylinder set with axis nearly horizontal like a rotary dryer and with a current of air passing through the cylinder so as to partially cool the clinker by the time it reaches the lower end of the cooler.

After cooling so as to be workable the clinker is taken by carriers to the grinders, where it is reduced to fine powder. This is done by several different classes of machinery in different plants and is usually accomplished by running through at least two machines, in one of which partial reduction is made and in the other the fine grinding. At some point during the grinding it is customary to introduce a small charge of gypsum or plaster of Paris (sulphate of lime) for the purpose of

controlling the rate of setting and neutralizing the effect of the presence of small proportions of free lime.

After grinding, the cement is exposed to the air for the purpose of allowing any free lime that it may contain to become air-slaked, after which it is carried to storage-bins or is put in barrels or sacks for shipment. In some instances keeping it for a time in storage-bins is relied upon for aeration, while in others aeration is omitted altogether.

The manufacture of Portland cement requires great care in the proportioning of the materials as well as in its subsequent manipulation. Each material must be studied in order to determine the best composition to give the mixture and the proper degree of burning to secure the best results, and these operations must be very closely controlled by frequent laboratory tests if high-grade cement is to be made.

Art. 12. Portland Cement.

The term *Portland Cement* is usually limited to material containing a high percentage of lime and burned at a high temperature. It is usually low in alumina and magnesia. In order to make a good cement of this character it is necessary that the ingredients be very accurately proportioned and that the material be very homogeneous. This requires ordinarily the pulverization of the raw materials and their uniform incorporation into the mixture in a finely divided state.

The Committee on Standard Specifications for Cement of the American Society for Testing Materials in 1904 suggested the following definition for Portland cement:

"This term is applied to the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials, and to which no addition greater than 3% has been made subsequent to calcination."

The Association of German Portland Cement Manufacturers in 1903 adopted the following definition:

"Portland cement is a hydraulic cementing material with a specific gravity of not less than 3.10 in the calcined condition, and containing not less than 1.7 parts by weight of lime to each one part of silica + alumina + iron oxide, the material being prepared by intimately grinding the raw ingredients, calcining them to not less than clinkering temperature and then reducing to proper fineness."

These definitions imply that Portland cement is an artificial mixture of materials to secure proper composition. All Portland cements made in the United States are of this character, but in France and Belgium certain cements are made and sold as Portland cements by burning natural rock approximately of proper composition for Portland cement without pulverization. This cement is not usually of high grade and is often called "Natural Portland Cement."

The action of Portland cement seems to depend upon the formation, during the burning, of certain silicates and aluminates of lime which constitute the active elements of the cement, the other ingredients being considered in the light of impurities. The ideal cement would be that in which the proportion of lime is just sufficient to combine with all the silica and alumina in

the formation of active material. If there be a surplus of clay beyond this point, it forms inert material. Any surplus of lime remains in the cement as free lime and constitutes one of the chief dangers in the use of cement, as, although it may not prevent the proper action of the cement when used, it may cause the mortar to afterward swell and become cracked and distorted as the lime slakes.

As perfect homogeneity is not attainable in practice, it is always necessary that the clay be somewhat in excess in order that free lime be not formed. The amount of excess of clay necessary evidently depends upon the thoroughness of the process used in manufacture and the evenness which may be reached in the mixture of raw materials.

The hydraulic index of Portland cement varies from about 42/100 to 60/100. The value of the index is affected by the relative proportions of silica, alumina, and iron oxide contained by the cement as the equivalent weights of these oxides differ. The normal composition of Portland cement is usually within the following limits:

Silica..................	20	to	25	per cent.
Alumina...............	5	"	9	"
Iron oxide.............	2	"	5	"
Lime..................	59	"	65	"
Magnesia..............	0.5	"	3	"
Sulphuric acid..........	0.25	"	2	"

Table I, taken from Candlot,* gives analyses ot a number of representative European Portland cements,

* Ciment et chaux hydrauliques (Paris, 1891).

while Table II, collected from various sources, gives analyses of a few of the leading brands of American Portland cements.

TABLE I.

COMPOSITION OF PORTLAND CEMENTS.

	Silica.	Alumina.	Oxide of Iron.	Lime.	Magnesia.	Sulphuric Acid.	Loss on Ignition.	Silicious Sand.	Not Determined.
French cements	22.20	6.72	2.28	67.31	0.95	0.26	0.40	....	....
	23.50	7.75	2.95	64.07	0.58	0.60	0.85	....	....
	21.70	7.48	2.57	65.54	0.90	0.77	1.20	....	....
	23.40	7.36	2.84	63.70	0.95	1.02	0.80	....	....
	24.50	7.09	2.81	62.40	0.85	0.70	1.25	....	0.40
	25.40	6.65	2.75	61.60	1.08	0.84	1.10	0.60	....
	21.80	6.56	2.64	57.42	0.72	0.34	0.40	0.12	....
	24.25	5.20	2.30	63.61	0.79	0.68	2.40	0.70	0.07
	22.30	8.04	3.71	58.68	2.20	2.23	2.55	0.25	0.04
	23.25	7.44	2.10	62.55	0.92	1.06	2.75	....	....
	23.00	8.33	3.87	60.90	1.10	1.40	1.49	....	....
	24.60	7.98	2.51	59.10	1.25	1.05	3.40	....	0.11
English cements	23.15	7.83	3.37	61.40	1.07	1.47	1.45	....	0.24
	23.30	7.65	3.10	62.20	1.04	1.06	1.60	....	0.05
	23.15	7.88	3.37	61.30	0.33	1.10	2.95	....	....
	23.70	7.80	3.40	59.36	0.55	1.25	4.10	....	....
	22.25	8.22	3.38	60.48	1.00	1.35	3.00	0.45	....
	21.95	7.99	3.91	59.08	1.04	1.52	4.35	0.35	....
	21.60	6.30	4.30	62.72	0.98	1.02	2.95	0.30	....
	21.35	7.15	3.75	62.16	0.95	1.06	3.20	0.25	0.13
	20.30	8.63	3.37	59.92	1.06	1.45	4.25	0.40	0.62
	23.30	8.13	2.67	60.48	0.60	1.20	3.90	....	....
	23.60	9.73	2.97	59.76	0.60	0.68	2.55	....	0.11
	24.05	8.69	3.31	59.69	0.90	1.47	1.85	....	0.25
	23.50	8.43	3.47	59.64	0.97	1.78	1.80	0.60	....
German cements	22.60	7.01	4.04	63.11	1.79	0.37	1.08	....	....
	21.75	8.16	3.64	63.39	2.30	0.51	0.25	....	....
	21.30	10.60	3.60	62.23	1.44	0.68	....	....	0.15
	24.85	6.07	2.43	64.40	1.26	0.51	....	....	0.48
	22.80	6.30	2.70	66.40	1.08	0.63	....	....	0.09
	23.70	5.25	2.70	67.18	1.00	1.40	....	....	....
	22.40	7.30	2.70	62.83	1.21	1.58	2.25	0.10	....
	22.80	7.46	2.84	63.28	1.24	0.98	1.55	0.20	....
	22.25	7.85	5.30	58.12	2.08	1.05	3.35	0.25	....
	20.80	8.66	3.64	62.52	1.68	0.89	1.85	0.10	....
Belgian cements	24.85	6.45	2.70	61.44	0.70	1.03	2.95	....	....
	24.50	8.51	2.84	60.03	0.88	1.54	1.20	0.60	....
	24.30	6.13	3.47	60.19	0.70	1.13	2.70	1.30	0.08
	23.80	6.39	2.51	62.32	0.72	1.17	2.94	....	0.14
	26.10	5.79	2.61	62.44	0.79	0.85	1.35	....	0.07
	24.30	5.33	2.67	64.12	0.72	0.74	1.95	....	0.17

A large number of analyses of European Portland cements are given by Professor Tetmajer,* which show for the most part about the same range of variation as those already given.

Table II.

COMPOSITION OF AMERICAN PORTLAND CEMENTS.

	Silica.	Alumina.	Oxide of Iron.	Lime.	Magnesia.	Sulphuric Acid.	Alkalies.	Loss.
Sandusky	22.33	5.53	3.28	64.40	3.61		.....	.....
"	22.06	4.80	1.66	65.44	2.82	0.90	.....	.....
Atlas	21.30	7.65	2.85	60.95	2.95	1.81	1.15	1.41
"	21.96	8.29	2.67	60.52	3.43	1.49	.....	.....
Buckeye	21.30	6.95	2.00	62.30	1.20	0.98	.....	4.62
"	20.75	13.50		62.25	0.25	0.25	2.25	.....
Giant	23.36	8.07	4.83	58.93	1.00	0.50	0.50	2.46
"	19.92	9.83	2.63	60.32	3.12	1.13	.....	.....
Lehigh	22.96	6.78	2.54	63.95	2.94		.....	.....
"	22.13	9.56		62.63	2.51	1.49	.....	.....
Empire	22.04	6.45	3.41	60.92	3.53	2.25	.....	.....
"	20.80	7.39	2.61	64.00	.....	.....	.....	.....
Alpha	20.38	.....	.....	63.30	2.86	1.13	.....	1.75
"	22.62	8.76	2.66	61.46	2.92	1.52	.....	.....
Edison	20.14	7.51	3.33	62.71	2.34	1.64	.....	.....
Saylors	21.25	8.25	4.21	61.25	1.50	1.38	2.00	.....
Red Wing	22.50	6.20	2.50	64.80	0.75	1.15	.....	.....
Yankton	22.00	7.74	4.61	59.50	0.90	0.80	1.20	.....
Red Diamond	19.91	13.63		63.82	0.83	1.16	.....	.....
Golden Gate	22.40	10.76		63.10	1.22	1.15	.....	.....
South Bend	22.30	7.21	3.79	59.24	3.03	1.47	.....	.....

Professor Le Chatelier has made a very careful study of the constitution of Portland cement by analyzing sections of clinker under the microscope, as well as by studying synthetically the various compounds of the

* Methoden und Resultate der Prüfung der Hydraulischen Bindemittel (Zurich, 1893).

principal ingredients. He concludes * that the tricalcic silicate, SiO_5Ca_3, is the only silicate that is really hydrualic and that it is the essential active element in cement. In Portland cement he finds it to be the principal component, occurring in cubical crystals. It is formed by combination of silica and lime in presence of fusible compounds formed by the alumina and iron.

"The dicalcic silicate, SiO_4Ca_2, possesses the singular property of spontaneously pulverizing in the furnace upon cooling. This silicate does not possess hydraulic properties and will not harden under water, but it is rapidly attacked by carbonic acid, forming carbonate of lime, and thus contributes something to the final hardening of mortar employed in air. The admixture of magnesia to form the double silicate of lime and magnesia, SiO_4MgCa, prevents the pulverization. This silicate is of no value for cement.

"At a very high heat the tricalcic silicate is decomposed into the dicalcic silicate and free lime, thus becoming inert."

"There are various aluminates of lime, all of which set rapidly in contact with water. The most important is the tricalcic aluminate, $Al_2O_6Ca_3$.

"With Portland cement a fusible silico-aluminate of lime, $2SiO_2,Al_2O_3,3CaO$, is formed, identical with that which forms the essential element of blast-furnace slag, with a portion of iron replacing alumina. This compound is inert under the action of water and does not seem to be attacked by carbonic acid. Its useful

---

*Annales des Mines September, 1893.

function is to assist the combination of silica with the lime.

"This silico-aluminate, which is crystallzed in Portland cement on account of slow cooling, is in a vitreous condition when the cooling is sufficiently brisk, as in the case of blast-furnace slag precipitated into cold water. It combines with hydrate of lime in setting, and gives rise to the hydrated silicates and aluminate of lime identical with those formed during the setting of Portland cement. It is these properties upon which are based the manufacture of slag cement."

Prof. Le Chatelier gives two limits within which the quantity of lime in Portland cement should always be found. These are, that the proportion of lime should always be greater than that represented by the formula

$$(1) \qquad \frac{CaO+MgO}{SiO_2-Al_2O_3-Fe_2O_3}=3,$$

and that it should never exceed that given by the formula

$$(2) \qquad \frac{CaO+MgO}{SiO_2+Al_2O_3-Fe_2O_3}=3.$$

The symbols in these formulas represent the number of equivalents of the substances present, not the weights. One third the number of equivalents of sulphuric acid should be added to the denominator in each case.

This is based upon the theory that the essential ingredients of the cement are the tricalcic silicate and aluminate of lime and the silico-aluminate already mentioned. Formula (1) represents the point at which the

amount of lime present would be just sufficient to form the tricalcic silicate and the silico-aluminate, no tricalcic aluminate being formed. If less lime than this be present, the bicalcic silicate would be formed.

Formula (2) represents the point at which the amount of lime would be sufficient to form the tricalcic silicate and aluminate to the exclusion of the silico-aluminate. If more lime than this be present, it will remain in the form of free lime.

It is also stated by Prof. Le Chatelier that for Portland cement of good quality formula (1) usually gives 3.5 to 4, and formula (2) gives 2.5 to 2.7 as a result.

Dr. Erdmenger considers* that the equations are not borne out by experience, as they involve the assumption that magnesia may be considered as lime. It is also pointed out that the formation of the bicalcic silicate depends upon the temperature of burning, and, according to Prof. Le Chatelier, the tricalcic silicate may be decomposed and become inert at a sufficient temperature.

Dr. Erdmenger also states that the powdering upon cooling may in some instances be prevented by cooling suddenly, as by plunging into cold water, and that when so treated the material does not become inert.

The examination of a considerable number of analyses of good Portland cement shows that the requirements of these formulas are commonly met in practice, and that the maximum in formula (2) is approached somewhat closely (from about 2.5 to 2.8). The minimum of formula (1) is, however, not usually approached by good

* Journal Society of Chemical Industry, XI, 1035.

cements, which give results varying from about 3.5 to 4.5.

Newberry's Investigations.—Messrs. S. B. and W. B. Newberry have made a careful investigation of the constitution of Portland cement following the method of forming, in the laboratory, compounds of silicas and alumina with lime and studying their properties and the effect of varying proportions.*

Silicates of lime were formed of pure precipitated chalk and quartz ground to impalpable powder and burned at an intense white heat. The dicalcic silicate, $SiO_2.2CaO$, as in Le Chatelier's experiments fell to powder upon cooling, but when suddenly cooled by quenching with water this was prevented and the clinker obtained upon being ground gave a white powder, which, when mixed with water, set slowly and became fairly hard in one day, and was quite sound. The mixture, $SiO_2.2\frac{1}{2}CaO$, gave a white clinker, sintered and much shrunken. The powder obtained by grinding this clinker hardened slowly in water, becoming fairly hard in seven days, very hard in six weeks, and continuing sound and hard.

The tricalcic silicate, $3CaO.SiO_2$, also gave a white clinker, the powder from which set fairly at one day, was rather soft after seven days, but quite hard at six weeks and was quite sound.

A mixture, $SiO_2,3\frac{1}{2}CaO$, clinkered but very little and was rather soft, but did not powder upon cooling. The powder obtained by grinding set hard when mixed with water, but became distorted and cracked after setting, although it was very hard after several weeks in water.

* Journal Society of Chemical Industry, Nov. 30, 1897.

The dicalcic aluminate, $Al_2O_3,2CaO$, gave a white powder when ground, which heated strongly when mixed with water and set in a few seconds. It was very hard after six weeks.

The aluminate, $Al_2O_3,2\frac{1}{2}CaO$, after being ground, heated strongly with water and set quickly. It became distorted and cracked after three days and was soft and cracked at six weeks.

The tricalcic aluminate, $Al_2O_3.3CaO$, heated strongly in water and set quickly, but became distorted and cracked in a short time, and disintegrated entirely when placed in water.

The conclusions reached by the Newberrys are as follows:

(1) Lime may be combined with silica in proportion of three molecules to one and still give a product of practically constant volume and good hardening properties, though hardening very slowly. With $3\frac{1}{2}$ molecules of lime to one of silica the product is not sound and cracks in water.

(2) Lime may be combined with alumina in the proportion of two molecules to one, giving a product which sets quickly but shows good hardening properties. With $2\frac{1}{2}$ molecules of lime to one of alumina the product is unsound.

"Assuming that the tricalcic silicate and the dicalcic aluminate are the most basic compounds which can exist in good cement we arrive at the following formula:

$$X(3CaO,SiO_2)+Y(2CaO,Al_2O_3),$$

in which X and Y are variable quantities depending

upon relative proportions of silica and alumina in materials employed.

"$3CaO,SiO_2$ corresponds to 2.8 parts of lime by weight to 1 of silica, while $2CaO,Al_2O_3$ corresponds to 1.1 parts of lime to one of alumina.

$$\therefore \ \% \text{ lime} = \% \text{ silica} \times 2.8 + \% \text{ alumina} \times 1.1.$$

This formula represents the maximum percentage of lime allowable.

Le Chatelier's maximum formula reduced to the same form, leaving out of account Fe_2O_3 and MgO, would be

$$\% \text{ lime} = \% \text{ silica} \times 2.8 + \% \text{ alumina} \times 1.6,$$

being based upon the tricalcic instead of the dicalcic aluminate.

Newberry differs from Le Chatelier in concluding that the percentages of Fe_2O_3 and MgO present need not be considered in determining the proper percentage of lime for Portland cement.

As perfect uniformity in the mixture of the ingredients is unattainable in the manufacture of cement it is necessary that the percentage of lime be somewhat less than the maximum given to avoid unsoundness in the cement. Newberry recommends * that the formula for practical use be changed to

$$\% \text{ of lime} = \% \text{ of silica} \times 2.7 + \% \text{ of alumina} \times 1.0.$$

The composition of commercial cement is also some-

* Taylor and Thompson's "Concrete," p. 58.

what affected by the additional silica derived from the fuel with which it is burned. This tends to slightly lower the per cent of lime in the finished cement.

According to M. Bonnami a sort of grappiers is thus formed, as with hydraulic lime, particles being thus produced less basic than the rest of the cement and of the character of puzzolana. This material is distributed through the cement in grinding and tends to slightly raise the hydraulic index. It is inert of itself, but may act like a puzzolana in combining with lime in the final hardening of the cement.

Richardson's Investigations.—The studies of Le Chatelier and the Newberrys have been of great value in extending knowledge of the composition and action of Portland cement. Mr. Clifford Richardson has made a further investigation into the constitution of cements which is of much importance in arriving at a better understanding of the subject.

Mr. Richardson made microscopic examinations of cement and of the various compounds which enter into it, prepared synthetically. He found * that three definite silicates of lime, SiO^2CaO, $SiO_2,2CaO$, and SiO_23CaO, appear to exist, the two more basic ones being strongly differentiated from each other by their optical properties. He also found four definite aluminates, Al_2O_3,CaO, $2Al_2O_33CaO$, Al_2O_32CaO, and Al_2O_33CaO. The silico-aluminates considered by Le Chatelier to be important in Portland cement were prepared by him and "found not to be definite chemical compounds, nor to correspond in any way with any of the mineral entities found in indus-

* The Engineering Record, Aug. 13, 1904.

trial clinker. They are in fact only solid solutions of aluminates in silicates of indefinite structure."

Törnebohm had made a microscopic study of Portland-cement clinker and found four distinct mineral constituents, named and described as follows:

"*Alit* is the preponderating element, and consists of colorless crystals of rather strong refractive power, but of weak double refraction.

"*Belit* is recognized by its dirty-green and somewhat muddy color and by its brilliant interference colors. It is biaxial and of high index of refraction. It forms small round grains of no recognized crystalline character.

"*Celit* is recognized by its deep color, brownish orange. It fills the interstices between the other constituents, being the magma or liquid of lowest freezing-point out of which the alit is separated. It is strongly double refractive, that is to say, gives brilliant colors when examined between crossed nicol prisms.

"*Felit* is colorless. Its index of refraction is nearly the same as that of belit and it is strongly doubly refractive. It occurs in the form of round grains, often in elongated form, but without crystalline outline. Felit may be entirely wanting.

"Besides these minerals an amorphous isothropic mass was detected by Törnebohm and Le Chatelier. It is called isothropic because it has no effect upon polarized light. It has a very high refractive index.

"Törnebohm adds the important fact that a cement 4% richer in lime than usual consists almost entirely of alit and celit.

Richardson's studies lead him to the belief that the

two principal constituents of Portland cement are alit and celit, as described above. Alit he considers to be a solid solution of tricalcic aluminate in tricalcic silicate, and celit a solution of dicalcic aluminate in dicalcic silicate. These solutions may be of varying degrees of concentration according to the relative proportions of silicates and aluminates present up to the point of saturation. These were studied synthetically, alit and celit being independently produced, and the two in combination as in Portland cement by combining the tricalcic silicate, SiO_23CaO, with varying proportions of dicalcic aluminate, $Al_2O_3.2CaO$. The limits of composition as found by Mr. Richardson for cement were from tricalcic silicate with no aluminate present to a molecular ratio of 7 tricalcic silicate to 3 dicalcic aluminate, $7(SiO_23CaO)3(Al_2O_32CaO)$.

Mr. Richardson's explanation of the formation of these solutions is as follows:

"Having determined that alit and celit are solid solutions of aluminates in silicates, the aluminates being present in less than an amount sufficient to make a saturated solution of aluminate in the silicate, it becomes of interest to consider how these solutions are formed during the conversion of a raw mixture or of a mixture of pure chemicals into a clinker. It would be simple to understand this if fusion took place in its formation, but this does not happen, the material is only sintered. If two gases are brought together they diffuse into each other with very great rapidity. If two liquids are poured one upon the other in layers without mixing, they diffuse more slowly. If solids are brought into contact it would be naturally assumed that diffusion would cease. Ex-

periments of Robert-Austen have shown that molecular mobility in solids exists, since when carefully polished surfaces of gold and lead are brought into contact and left under pressure for some months, at the ordinary temperatures, gold is diffused into the lead and the lead into the gold for an appreciable distance. Mixtures of the components which would produce a fusible wood metal when subjected to pressure at ordinary temperature become converted into this alloy. Anhydrous sulphate of soda and carbonate of barium also diffuse when brought into close contact with the formation of barium sulphate and carbonate of soda. It is not difficult to understand, therefore, how at a temperature of 1650° C. the particles of silica, alumina, and lime may diffuse below the melting-point of the resulting clinker to form a Portland cement, and the fact that such a clinker is stable depends not only on its composition, but upon the fact that the diffusion has been complete, even in material which is only sintered. Sintering, therefore, may be defined as diffusion at a temperature below the melting-point of the components or of the resulting solid solution. That diffusion under such conditions is surprisingly rapid is seen by placing a particle of ferric oxide on the surface of white Portland-cement clinker and then submitting it to a moderately high temperature. The rapid diffusion of iron through the white clinker can readily be noticed by the color which spreads through the mass. It is evident that the higher the temperature the more rapid the diffusion until it becomes very rapid on fusion. From this it may be concluded that the length of time during which it is necessary to expose any mixture of silica, alumina, and lime to a tem-

perature is a function of the temperature, and should be longer the lower the temperature."

The work of these investigators has greatly extended our knowledge of the constitution and properties of the various cement materials and made possible the fixing of proper composition for Portland cement within narrow limits.

Further investigation is, however, necessary to a full definite knowledge of the actions taking place in forming cement and of the rôle of the ingredients other than the three principal ones. The part played by magnesia is left in doubt, while iron oxide is supposed to act in a manner similar to alumina in forming cement. Newberry says: "Iron oxide combines with lime at a high heat and acts like alumina in promoting the combination of silica and lime. For practical purposes, however, the presence of iron oxide in a clay need not be considered in calculating the proportion of lime required."

This is based upon the supposition that the iron oxide is insignificant in amount.

ART. 13. NATURAL CEMENTS.

The term *Natural Cement* is commonly employed to designate a large number of widely varying products formed by burning natural rock without pulverization or the admixture of other materials. These cements are usually of higher hydraulic index than the Portlands, and consequently more lightly burned. The materials used for this purpose are limestones containing silica, alumina, and iron oxide in quantities greater than

would be needed for Portland cement. These materials vary greatly in composition and character, some being of such composition as to make Portland cement by increasing the content of lime, others carrying larger amounts of alumina or of magnesia than would be admissible in materials for Portland cement.

The quick-setting natural cements, or *Roman Cements* as they are called in Europe, are obtained by burning, at a low temperature, argillaceous limestones of rather high index. These cements are usually characterized by a very rapid set and slowness in gaining strength subsequently. The feeble burning gives incomplete reactions, and the formation of the silicates of lime is not so complete as in the heavily burned Portland cements. A considerable percentage of aluminate of lime is present, which is the cause of the quick set. Some unburned material is also commonly present in such cements, remaining as inert matter. Material of this character becomes inert when the temperature of burning is increased to the point where the chemical reactions would become complete.

Table III gives results of analyses of a number of the leading European Roman cements collected from various sources, and showing the ordinary range of variation in composition for good material.

The slow-setting natural cements of Europe are often known as *Natural Portland Cements*. These are often of a composition quite similar to Portland cement, but usually have a slightly higher hydraulic index and are given a somewhat lighter burning. They are, however, more heavily burned than the Roman cements. Limestones in nature are not so homogeneous as the artificial

mixtures used in making Portland cement, and the proportion of lime cannot be so great as in the more homogeneous

TABLE III.

COMPOSITION OF EUROPEAN ROMAN CEMENTS.

	Silicious Sand.	Silica.	Alumina.	Iron Oxide.	Lime.	Magnesia.	Sulphuric Acid.	Loss on Ignition.	Not Determined.
1	....	22.60	8.90	5.30	52.69	1.15	3.25	6.11	....
2	6.00	24.80	7.00	4.80	44.12	2.08	3.60	7.50	0.10
3	....	21.70	8.29	3.71	52.68	3.52	3.56	6.20	0.34
4	....	23.60	7.99	4.31	57.40	1.50	2.10	2.75	0.35
5	....	21.80	10.03	3.77	55.00	2.80	2.74	3.75	0.11
6	2.00	26.80	10.39	4.61	46.10	1.72	1.74	6.40	0.24
7	10.70	30.80	7.82	5.13	33.04	0.93	2.90	8.20	0.48
8	2.40	25.45	9.25	3.85	47.95	1.45	0.70	8.95	....
9	....	29.55	8.35	4.10	47.50	3.85	1.35	5.30	....
10	....	21.00	8.40	5.10	52.05	1.00	2.50	9.95	....
11	....	23.40	12.90	3.30	47.70	1.05	3.30	8.35	....
12	0 85	29.05	7.95	3.75	46.05	2.80	1.10	8.45	....
13	....	25.85	9.10	4.10	51.60	0.85	1.50	7.00	....
14	4.35	27.35	7.73	3.85	50.25	1.05	0.55	4.85	....
15	....	25.85	10.00	4.85	54.20	1.65	1.00	2.45	....
16	....	29.10	12.50	4.65	48.60	1.70	1.90	1.55	....
17	3.40	24 65	11.35	5.25	50.45	1.15	1.25	2.50	....
18	0.50	20.00	8.40	5.70	52.05	0.95	2.80	9.60	....
19	2.60	27.10	4.10	3.75	48.70	0.65	0.95	12.15	....
20	....	28.06	6.65	3.30	47.79	1.08	1.66	10.44	...
21	....	27.54	9.25	3.80	54.58	0.50	0.64	3.69	....
22	....	20.54	8.72	3.23	51.85	2.31	3.93	9.28	....
23	....	21.04	12.72	4.04	51.38	1.20	5.51	3.65	....
24	....	21.29	9.36	3.51	51.74	4.24	6.01	3.22	....
25	....	23.35	9.69	2.96	54.71	1.08	1.95	4.31	....
26	....	20.60	9.92	2.56	52.42	3.91	6.06	3.30	....
27	....	28.36	12.12	1.57	47.28	2.24	2.00	4.52	....
28	....	25.64	8.76	2.15	44.87	1.93	5.11	10.16	....
29	....	25.70	9.26	3.38	50.86	1.54	1.51	6.67	....
30	....	29.74	11.92	3.68	42.98	2.08	2.34	6.20	....
31	....	22.14	8.74	3.69	58.41	2.02	2.90	2.12	....
32	....	23.35	8.20	3.74	57.94	1.63	2.98	2.82	....

mixtures without danger of producing an objectionable quantity of free lime in the cement. The use of material

of this character, therefore, requires much care in order to produce good results. As the hydraulic index becomes greater the homogeneity becomes less important, as free lime becomes less likely to occur and less dangerous, and irregularities only have the effect of increasing the quantity of inert matter, which causes mortar made from the cement to gain strength much more slowly than with Portland cement of low index. It is to be observed that the material spoken of as inert, and which delays the gain in strength in the early period of hardening, may not be altogether inert, and may contribute to the final strength of the cement, as it is of a puzzolanic character and perhaps ultimately combines with the hydrated lime in the mortar.

These cements occupy an intermediate position between the artificial Portland cements and the Roman cements, and may approach either in composition. In fact, the same raw material may frequently produce either—if burned lightly, giving the quick-setting Roman cement, or burned more heavily, a slow-setting natural Portland. Heavy burning increases the amount of silica combined with lime at the expense of the aluminates, thus relaxing the rapidity of set and increasing the early strength of the mortar.

The *Magnesian Natural Cements* are those in which a portion of the lime of the Roman cement is replaced by magnesia. Very little is known as to the action of the magnesia in these cements. It seems probable that the magnesia replaces lime or combines with it in the formation of double silicates and aluminates, and that it bears some part in the setting and hardening of the mortar. That certain magnesian salts possess hydraulic

properties is well known, their action according to M. Fremy being probably much slower than the corresponding lime-salts.

The action of cements of this class is somewhat similar to that of Roman cements: they gain strength very slowly, but may be either quick- or slow-setting. The composition of the magnesian cements varies from that of the Roman cements to one in which the proportion of magnesia is as large as that of lime. As the proportion of magnesia to lime increases, the hydraulic index, considering magnesia as lime, frequently decreases and becomes less than would be admissible in Roman cement.

Magnesian cements are but little used in Europe, but in the United States they form the larger part of the natural cements in use, and many of them have been found by experience to be very useful and reliable materials. Table IV gives analyses of American natural cements from various districts, showing something of the range in composition of these materials.

As already stated, these cements are burned at a much lower temperature than Portland cement, in many the temperature being only about that which will decompose the carbonate of lime. The temperature of burning varies with the lime content of the material, being greater for those materials high in lime, and it seems probable that the lime and possibly the magnesia is wholly combined with the silica and alumina present, this taking place at a lower temperature as the proportion of lime is less. If the heat be increased beyond the point necessary to effect this initial combination, less basic compounds result, rendering the material inert.

TABLE IV.

COMPOSITION OF AMERICAN NATURAL CEMENTS.

District.	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	Alk.	Loss.
Utica.........	27.60	10.60	0.80	33.04	17.26	7.42	2.00
"	34.66	5.10	1.00	30.24	18.00	6.16	4.84
Louisville......	26.40	6.28	1.00	45.22	9.00	4.24	7.86
"	22.54	8.28	2.14	42.31	5.39	2.82	......
"	23.29	5.96	2.16	41.28	15.39	1.98	......
Potomac......	28.02	10.20	8.80	44.48	1.00	0.50	7.00
"	30.22	8.38	5.38	39.54	3.80	....	10.20
Hudson.......	27.98	7.28	1.70	37.59	15.00	7.96	2.49
"	28.91	10.96	4.68	34.64	14.82	1.80	4.50
"	31.28	11.30		36.67	14.35	....	4.27
"	27.30	7.14	1.80	35.98	18.00	6.80	2.98
"	30.78	8.68		34.14	19.61	1.62	3.57
Akron.........	22.62	7.44	1.40	40.68	22.00	2.23	3.63
"	26.69	7.21	1.30	43.12	19.55	1.13	1.00
"	20.75	10.02		37.54	26.14	2.12	4.58
Milwaukee.....	23.16	6.33	1.71	36.08	20.38	5.27	7.07
"	25.00	4.00	2.80	33.40	22.60	2.51	9.50

The rock from which these cements are made differs greatly in character in the same locality, and in the different strata of the same quarry. In some of the works the nature of the product is regulated by mixing in proper proportions the clinker obtained by burning the rock from different strata. Each portion of rock must be burned in such degree as is suited to its composition, and hence as the material is not pulverized before burning it must be burned separately and mixed afterward. To produce uniformly good cement, therefore, requires close and careful attention; and for this reason there is often considerable difference in the quality of cement made by works in the same locality and from very similar material.

Cement of high index, unlike Portland cement, is usu-

ally materially changed by age. When these cements are kept exposed to the air for a considerable length of time, they gradually become slower-setting and perhaps eventually lose the power of setting altogether, sometimes becoming puzzolana, which again becomes active cement by reburning.

Art. 14. Slag Cements.

Slag-cement is formed by the admixture of slaked lime with ground blast-furnace slag. The slag has approximately the composition of a hydraulic cement, but lacks a proper proportion of lime to render it active as a cement. These cements are sometimes called puzzolana cements, the slag used being of the same nature as the puzzolana commonly employed in making lime hydraulic.

The method employed in forming slag cement is to cool the slag suddenly by plunging it into a current of water as it emerges from the furnace. This makes the slag granular, and causes it to retain the heat of crystallization, thus rendering its elements more ready to enter into combination in presence of water. This also modifies to some extent the chemical composition of the slag, largely eliminating the sulphur.

Experience in Europe shows that the slag must be basic in order to be of use in making cement. Professor Tetmajer* arrives at the conclusion that slags in which the ratio $\frac{\text{lime}}{\text{silica}}$ is unity are not suitable, and that above this proportion the value of the product increases with

* Annales de les Construction, Juillet, 1886.

this ratio. He also finds that the best results are obtained from slags giving a ratio

$$\frac{Al_2O_3}{SiO_2} = 45/100 \text{ to } 50/100.$$

M. Prost * states that a considerable amount of sulphur may be unobjectionable in slag cements, and mentions a case where good results had been obtained with sulphurous slag, the only effect being discoloration attributed to sulphide of iron. He also concludes that a slag is most advantageous for this purpose which is most rich in lime and alumina.

Slags in actual use for the manufacture of slag cement vary considerably in composition. The ratio $\frac{\text{lime}}{\text{silica}}$ ranges from about 1.30 to 1.80, and the ratio $\frac{\text{alumina}}{\text{silica}}$ from 0.40 to 0.90. In most instances these two ratios vary together, that is, the high-lime ratio is found in the same material as the high-alumina ratio.

It is very important in slag cements that the slag be ground very fine, and be very intimately mixed with the lime. The lime is slaked and bolted and then ground mechanically with the slag so as to insure thorough incorporation into the mixture.

In consequence of the necessity of attaining extreme pulverization of the slag, it is necessary to first dry it. The water which serves to make it granular remains to some extent between the grains and makes bad lumps at time of grinding. It has been attempted to sub-

* Annales des Mines, 1889, vol. II, p. 158.

stitute quicklime for slaked lime and use this water for slaking, but unsuccessfully, the slag combining to some extent with the lime and thus weakening the cement, while particles of quicklime being left in the cement cause swelling of the mortar after setting.

In some of the European plants the slag is finely ground and bolted through fine sieves before being mixed with the lime, but more common practice is to slake and bolt the lime and then mix with the granular slag before grinding, or to do the pulverizing of the slag in two stages and make the mixture between the first and second grinders.

The lime may advantageously be kept for some time after slaking before being used, as this insures the complete reduction of the quicklime, but the slag seems to deteriorate when kept long after grinding. Fat lime is commonly employed for this purpose, but there seems to be an advantage in using meagre lime on account of the mortar being less likely to crack when used in the air. M. Prost found that there was no advantage to the strength of the cement in using hydraulic lime, but that the hydraulic lime gave better resistance in the air. Slag cement usually seems to act better under water than in the air, and most European authorities have found it likely to crack in the air.

There is, however, considerable difference between different cements in this particular, and some experimenters find no difficulty with the use of the material in the air. It is essentially a hydraulic material, and it is especially important that it be kept damp during the early period of hardening, in order that the water necessary to its proper hardening may not evaporate.

The composition of slag cement usually differs from that of Portland in having a less quantity of lime, more silica and alumina, and more alumina in proportion to the silica.

Table V gives the composition of a number of sapmles of the leading European slag cements, taken from Candlot and Tetmajer.

TABLE V.

COMPOSITION OF SLAG CEMENTS.

	Silica.	Alumina.	Iron Oxide.	Lime.	Magnesia.	Sulphuric Acid.	Loss on Ignition.	Not Determined.
1	24.80	19.13	2.67	36.60	6.76	2.10	7.50	0.44
2	24.60	13.46	0.84	50.22	2.65	2.70	5.40	0.13
3	24.90	13.46	2.83	50.40	1.20	1.10	6.45	....
4	24.30	13.85	1.15	49.50	2.16	1.86	6.90	0.28
5	27.45	14.65	1.75	46.20	1.86	0.72	7.00	0.37
6	25.20	15.23	0.77	50.00	1.35	0.72	6.50	0.23
7	20.40	18.59	0.41	50.07	0.50	0.08	8.30	....
8	18.30	18.07	0.34	53.16	0.64	0.18	8.07	....
9	22.35	12.83	0.64	55.61	2.17	0.27	4.01	....
10	27.35	9.13	1.50	50.28	5.72	0.40	2.59	....
11	20.35	14.05	0.33	50.26	2.68	2.39	6.99	....
12	18.69	9.20	2.14	46.36	4.92	1.25	12.19	....
13	19.87	14.84	0.80	48.54	2.44	1.00	8.41	....
14	18.11	15.54	0.92	54.72	0.54	0.37	8.64	....
15	20.94	14.85	1.03	48.18	3.58	1.69	7.22	....
16	19.24	17.15	1.07	54.21	0.81	0.39	6.39	....

Slag cement is usually slow-setting, but the activity varies greatly with the circumstances of use. The rapidity of action is greater as the proportions of lime and alumina increase.

M. Prost states that slag cement is sensitive to the action of frost and should not be used in freezing weather; while Mr. Redgrave declares that it resists frost better than Portland—showing a difference of experience in France and England.

Mr. Redgrave also says that it may be kept a long time without injury, and if kept free from moisture, that it undergoes no change whatever; while M. Bonnami states that exposed to air in powder it rapidly loses its hydraulic properties, probably through carbonization.

Art. 15. Mixed Cements.

The term *Mixed Cement* is sometimes used to include a considerable number of cements which are formed by a mixture of various products occurring at works where other cement is made. These mixtures may be made either for the purpose of cheapening the product or of imparting to it certain desired qualities. They consist of admixtures of different grades of cement, of the overburned or underburned portions of clinker, or of foreign material added to the cement.

Slag cements and certain natural cements which, like some of the Rosendales, are made by mixing different grades of clinker are sometimes included under this head, but are not what is usually meant by the term.

Mixed cements differ so widely in character that no general discussion of their attributes is possible. Their values depend upon the care used in selecting, proportioning, and incorporating the ingredients, and each works has its own method of manufacture. In some cases, light-burned Roman cement is made slow-setting by the admixture of grappiers obtained in the slaking of hydraulic lime, with sometimes an addition of Portland cement. The overburned clinker from the manufacture of Portland cement is also sometimes utilized by

being mixed with natural cement, a certain amount of Portland cement being added to bring up the initial strength and reduce the rapidity of set.

Cement of this kind is usually sold under the designation of Portland or natural cement, and not according to its real character. Some of them when carefully and regularly made give good results in practice.

Art. 16. Grappiers Cement.

Grappiers cements are made by grinding to powder the grappiers left from the slaking and bolting of hydraulic lime. Very great care is necessary in eliminating all of the free lime from the grappiers by thorough slaking, the operation of slaking and bolting being repeated several times. The grappiers includes the underburned stone, and overburned material formed in contact with the fuel, as well as a certain amount of hard-burned material of too high hydraulic index to slake, and similar in composition and action to Portland cement. This latter is the effective portion of the cement, and it predominates in grappiers of good quality.

These cements are usually of low index and very slow-setting. They are liable to contain free lime unless carefully handled and usually require exposure to the air after grinding to permit them to become air-slaked.

At Teil the grappiers are passed through coarse grinders, which serve to remove all the soft parts. It is then bolted, allowed to air-slake for a month, then bolted again. Finally the parts resisting slaking are ground, steam

being present to slake the particles of free lime, after which it is air-slaked before packing for shipment.

ART. 17. SAND CEMENT.

Sand cement is the name given to material formed by grinding together Portland cement and sand to an extremely fine powder and a very intimate mixture. It is claimed that a very considerable amount of sand may thus be mixed with the cement without materially reducing its strength, and that the sand cement so made may still be mixed with the usual proportions of ordinary sand and give good results in use.

It is said that the additional grinding given the cement in pulverizing the sand reduces the cement to impalpable powder, thus increasing its power of "taking sand." Experiments also seem to indicate that if sand be powdered separately, a certain amount may be mixed with cement without serious injury to mortar made from the cement.

CHAPTER III.

THE SETTING AND HARDENING OF CEMENT.

ART. 18. THE SETTING OF CEMENT.

WHEN cement powder is mixed with water to a plastic condition and allowed to stand, it gradually combines into a solid mass, taking the water into combination, and soon becomes firm and hard. This process of combination amongst the particles of the cement is known as the *setting* of the cement.

Cements of different character differ very widely in their rate and manner of setting. Some occupy but a few minutes in the operation, while others require several hours. Some begin setting immediately and take considerable time to complete the set, while others stand for a considerable time with no apparent action and then set very quickly.

The points where the set is said to begin and end are necessarily arbitrarily fixed, and are differently determined—usually by trying when the mortar will sustain a needle carrying a specified weight. The beginning of set is usually supposed to be when the stiffening of the mass first becomes perceptible, and the end of set is when the cohesion extends through the mass sufficiently to offer such resistance to any change of form as to cause

rupture before any perceptible deformation can take place.

It is sometimes stated that the chemical change involved in setting is an instantaneous occurrence at about the time we call the beginning of set, and that the gradual hardening then begins and is a continuous process until the maximum strength is reached. However this may be, with some cements a quite noticeable change suddenly shows itself at about this time in the disappearance of water from the surface of the mortar and the sudden stiffening of the mass.

ART. 19. THE HARDENING OF CEMENT MORTAR.

After the completion of the setting of the cement the mortar continues to increase in cohesive strength over a considerable period of time, and this subsequent development of strength is ealled the *hardening* of the cement.

The process of hardening appears to be quite distinct from, and independent of, that of setting. A slow-setting cement is apt, after the first day or two, to gain strength more rapidly than a quick-setting one; but it does not necessarily do so. The ultimate strength of the cement is also quite independent of the rate of setting. A cement imperfectly burned may set more quickly and gain less ultimate strength than the same cement properly burned, but of two cements of different composition the quicker-setting may be the stronger.

There is as wide variation in the rate of hardening of different cements as in the rate of setting; some gain

strength rapidly and attain their ultimate strength in a few days, while others harden more slowly at first and continue to gain in strength for several years. The rate of early hardening gives but little indication of the ultimate action of the cement, as the final strength of the mortar may be the same however rapidly the strength is attained.

Portland cement usually hardens more rapidly and gains its maximum strength more quickly than natural cement, and also, as a rule, the Portland cement attains greater final strength when used in the same manner. Of two cements of the same class, however, it is not safe to infer that that which most rapidly gains strength will prove the stronger and more permanent material; in fact, where an abnormally high strength is shown in a few days the presumption as to final strength is against the cement giving such result and in favor of one hardening at a more moderate rate.

The rate at which cement should harden for a given use depends, of course, upon the necessity of developing early strength in the work. For many purposes, such as most subaqueous construction, high early strength is quite desirable if not necessary; but for most engineering work a very rapid hardening does not seem necessary and better results may often be obtained by the use of a material of more gradual action.

Art. 20. Chemical Theory.

Very little is definitely known concerning the chemical reactions which take place in the process of setting and hardening of cement mortars. Many theories have been proposed to account for the phenomena by different observers, based mainly upon the study of the properties of various compounds of lime, silica, and alumina formed synthetically. Chemical analysis shows the proportions of the various elementary substances of which the cement is composed, but not their state of combination; and the action of a cement may be greatly modified by altering the condition in which the ingredients exist, through changing the manipulation in manufacture, without altering their relative quantities.

Fremy considered Portland cement to be very complex in composition, and ascribed the setting to the action of lime upon certain puzzolanic compounds composed of double silicates of lime and alumina, the calcination of the clay giving rise to a porous material which absorbs the lime by capillary affinity.

Landrin concluded that a substance corresponding to the formula $3SiO_2,5CaO$ is found in both Portland cement and puzzolana, and he considered this to be the active element in the hardening of cement, although he states that aluminate of lime contributes to the setting and accelerates that action.

Prof. Le Chatelier, from his study of Portland cements, explains the phenomena of setting by showing that certain salts, including the aluminate and silicate of lime which form the active elements of Portland cement,

while soluble in an anhydrous state, form insoluble salts when hydrated. When they come into contact with water in mixing mortar the anhydrous salt enters into solution; then, becoming hydrated, the hydrate is precipitated from the saturated solution in a crystalline form. Those salts which are thus capable of being dissolved in an anhydrous state and then becoming hydrated arrive at stability in two ways—by decomposition and by combination.

The tricalcic silicate, which is the essential element of Portland cement, is decomposed in presence of water to a hydrated monocalcic silicate and a hydrate; thus

$$SiO_5Ca_2 + Aq = SiO_2,CaO,2.5H_2O + 2CaO,H_2O.$$

The monocalcic silicate crystallizes in the form of needle-like crystals and the hydrate in hexagonal lamina visible to the eye. The tricalcic aluminate is hydrated by simple combination with the water.

$$Al_2O_6Ca_3 + Aq = Al_2O_3,3CaO,12H_2O.$$

The double silicate, $2SiO_2,Al_2O_3,3CaO$, of alumina and iron is thought to be quite inert in Portland cement, and to merely serve the purpose of assisting the combination of the silica and lime by acting as a flux during burning. It seems, however, to be an active element in slag cement, forming by combination with lime in presence of water the same compounds that are produced in the setting of Portland cement. The difference in its action is explained by the fact that in the slow cooling of Portland cement the salt exists in crystalline form, while through the sudden cooling of the slag it is made vitreous, and is then in condition to be attacked by the lime.

The first setting of Portland cement is attributed to the hydrating of the aluminates and ferrites of lime, while the subsequent hardening is due to the slower progress of the hydration of the tricalcic silicate. The rapidity of set is therefore dependent upon the relative proportions of aluminates and silicates. When the burning is done at a low temperature, therefore, the aluminates, which are first formed, will cause a rapid set, while as the degree of burning becomes greater the aluminates give place to silicates, which cause the setting to become slower and the subsequent gain in strength greater. The aluminates are thought to add but little to the final strength of the mortar, as they are not permanent compounds, but are acted upon by water and various salts with which they are likely to come in contact in the work.

Cements of low hydraulic index harden more rapidly and gain their full strength earlier than those of high index. They are more nearly of the composition which according to the theory should give the highest proportion of active ingredients, while those of high index have a surplus of silica and alumina, forming inert material. It is perhaps questionable whether in all cases this so-called inert material is in reality inert in the final hardening of the cement. Sometimes those cements which from this cause harden very slowly continue to gain in strength over a long period, and ultimately surpass those which gain strength more rapidly in the beginning; and it is quite possible that this overclayed portion, which is of puzzolanic character, may bear an important part in the final hardening.

Most slow-setting cements have a period during which

they lose strength after hardening for several months, probably due to the decomposition of salts formed by the parts of too low hydraulic index during the burning. This loss of strength is usually temporary when the cement is of normal composition; but if it be overlined, the loss of strength may continue, to the final destruction of the mortar.

The experiments of M. Candlot indicate that the presence of carbonic acid is essential to the hardening of hydraulic cement mortar. He found that if the mortar were placed in distilled water frequently renewed it became gradually decomposed, and finally lost all coherence; but the presence of carbonic acid, as is common in all natural waters, prevented this action and caused proper hardening to take place.

Mr. Clifford Richardson offers the following explanation of the phenomena of setting and hardening of Portland cement, assuming the cement to consist of solid solutions, as indicated by Richardson's investigations (see Art. 12): *

"On the addition of water to a stable system made up of the solid solutions which composed Portland cement a new component is introduced which immediately results in a lack of equilibrium, which is only brought about again by the liberation of free lime. This free lime the moment that it is liberated is in solution in the water, but owing to the rapidity with which it is liberated from the aluminate, the water soon becomes supersaturated with calcic hydrate, and the latter crystallizes out in a network of crystals which binds the particles of unde-

* Engineering News, Jan. 26, 1905.

composed Portland cement together. From the characteristics of the silicates and aluminates it is evident that the latter are acted upon much more rapidly than the silicates and it is to the crystallization of the lime from the aluminates that the first or initial set must be attributed. Subsequent hardening is due to the slower liberation of lime from the silicates. If the lime is liberated more rapidly than it is possible for it to crystallize out from the water, expansion ensues and the cement is not volume constant.

"The set of Portland cement is almost entirely due to the decomposition of the alit alone. Examination of a thin section of a neat Portland-cement mortar will show that it contains large quantities of unattacked celit and a certain amount of unattacked alit. If the fractured ends of a neat Portland-cement briquette are held together by means of a rubber band and then immersed some time in water the pieces of the briquette will be found to have become cemented together owing to the setting of the portions of unacted cement on the surfaces of the fracture.

"The strength of Portland cement after setting is due entirely to the crystallization of calcium hydrate under certain favorable conditions, and not at all to the hydration of the silicates or the aluminates, since in this act of hydration nothing can take place which would tend to bind these silicates and aluminates together. Celit is certainly decomposed to but a slight degree in the process of setting. From this we may infer that the strongest cement is the one which contains the smallest amount of celit and such a conclusion is entirely justified by experience. The more high in lime a cement is

the greater its strength is known to be if it is thoroughly burned."

As already pointed out, cements high in lime (much alit) gain strength more rapidly than those low in lime (much celit), but it has frequently been observed that cements slow to gain strength are ultimately as strong or stronger than those which gain strength rapidly. This would seem to indicate that those compounds low in lime (celit) may play a more important part in the ultimate hardening of cement mortar than is commonly supposed.

ART. 21. INFLUENCE OF CALCIUM SULPHATE.

The action of sulphate of lime to slacken the rate of setting of Portland cement is well known. In Germany it has been common to utilize it, for the purpose of regulating the rate of set, by adding powdered gypsum to the cement.

Candlot* has made a careful study of the influence of sulphate of lime upon the action of Portland cement. He found that the increase in time required to set varied with the quantity of sulphate added, an addition to a quick cement of from 1 to 4 per cent being sufficient to change the time of set from a few minutes to several hours. Cement which has been made slow-setting by the addition of calcium sulphate becomes again quick-setting with age, more or less rapidly, as it is or is not exposed to the air. In some cases the cement by

* Ciment et Chaux Hydrauliques (Paris, 1891).

exposure soon becomes quick-setting, and then by longer exposure again becomes slow. When cement treated with the sulphate of lime has regained its quick action by exposure, it may again be made slow by the addition of a small quantity of lime. Fresh cement with sulphate of lime added, and setting slowly in consequence, will set rapidly if the mortar be mixed with a solution of the carbonate of soda.

"Cement having sulphate of lime added sets more rapidly when mixed with sea-water than with fresh water; and that which has been exposed and regained its former activity sets more rapidly when mixed wet than when mixed stiff.

"The addition of a small quantity of calcium sulphate to Portland cement augments the strength. When the mortar is kept in sea-water and the proportion of sulphate exceeds 1 or 2 per cent, the mortar cracks and perhaps disintegrates. When the cement containing the sulphate was kept in sacks during several weeks it showed less strength during the early period of hardening."

M. Candlot concludes from his experiments that the explanation of the action of sulphate of lime lies in the fact that in the presence of water the sulphate combines with the aluminate of lime, forming the compound $Al_2O_3,3CaO,2.5(SO_3CaO)$, which crystallizes with a large quantity of water. The action depends upon the fact that the aluminate is insoluble in lime-water, and, as most of the quick-setting cements contain a certain quantity of free lime, when the cement is gauged the lime at once enters into solution and prevents the action of the aluminate until the sulphate is combined with it. When the cement becomes old, the free lime becomes carbonized

and fails to prevent the immediate solution of the aluminate.

Aluminous cements burned at low temperatures often contain considerable aluminate of lime, and these may bear an addition of 5 to 10 per cent of sulphate without loss of strength. The proportion of sulphate must always be limited to what may be neutralized by the aluminates.

Art. 22. Influence of Calcium Chloride.

Candlot has also made a careful study of the effect upon the setting and hardening of cement mortar of chloride of calcium, either dissolved in the water with which the cement is mixed or that in which the mortar is immersed. He found that Portland cement gauged with water containing a few grammes per litre of chloride of calcium sets more slowly than if gauged with pure water; while if the solution of cholride be concentrated, 100 to 400 grammes per litre, the setting is very rapid.

"The influence of calcium chloride in weak solution upon the set of Portland cement may be attributed to the salts which determine the set entering into solution more slowly in that solution than in pure water. Hydrate of lime agitated with a large excess of water is dissolved much less in the chloride solution than in pure water, while with the aluminate of lime this result is much more marked.

"If cement of Vassy, quick-setting, be gauged with a solution of chloride of calcium, 20 to 40 grammes per litre, the setting is about the same as with pure water. If the cement be diluted to a fluid with the

same solution it will not set or harden. Portland cement treated in the same way hardens very slowly, but acquires a hardness comparable to that given by fresh water.

"Feeble solutions of chloride of calcium have no appreciable effect upon cements exempt from alumina, like certain grappiers cements composed almost exclusively of silicate of lime.

"From this the conclusions are drawn:

"1. That in Portland cement the aluminate exists in feeble proportions; that it acts in an energetic manner upon the set, but very little upon the hardening, which is caused by the silicate of lime.

"2. That in the Vassy cement the aluminate of lime is the essential element, and determines both the setting and the hardening; the rôle of the silicate being unimportant, especially during the early period of hardening.

"3. That in the phenomena of setting the relative quantities of the elements present determine the action. The solution of chloride in presence of a large quantity of the aluminate of lime perhaps does not hinder the hydration and crystallization; but if, on the contrary, a small quantity of aluminate be mixed in an excess of chloride solution, the action of that preponderates and the aluminate will not enter into solution.

"A weak solution of CaCl has the property of provoking the rapid hydration of lime. A cement containing an excess of free lime, gauged with pure water, swells and disintegrates under the slow expansive action of the free lime. The same cement gauged with a solution of CaCl, 30 to 60 grammes per litre, does not swell, because the lime is slaked before the set.

"As already stated, when Portland cement is mixed

with a solution of 100 to 400 grammes per litre CaCl it sets very quickly. This set is accompanied by a strong rise in temperature. This only occurs with a fresh cement. With an old cement the setting remains slow, no rise in temperature is produced, and the mortar swells and disintegrates.

"Mortar of cement gauged with a concentrated solution of CaCl is disintegrated if placed in water immediately after setting, but 15 or 20 hours afterward it may perhaps be submerged without loss of strength.

"The action of a concentrated solution CaCl upon Portland cement is due to the fact that aluminate of lime is attacked very energetically by that solution. While it is very slightly soluble in a feeble solution, it is dissolved in large quantities in a concentrated solution.

"When a fresh cement is agitated with a concentrated solution of CaCl it dissolves not only the aluminate, but the oxide of lime. The lighter the cement is burned, the more it will dissolve. When an old cement is agitated with the concentrated solution of CaCl the aluminate dissolves but very little."

Art. 23. Effect of Sand.

Cement is ordinarily employed in mortar formed by mixing it with sand, and the action of the mortar is necessarily largely affected by the nature and quantity of sand used.

When the cement is finely ground and the sand of good quality, a mortar composed of equal parts of each, as a general thing, finally attains a strength as high as, or higher than, the neat cement. Cements of different

characters, however, vary considerably in their power to "take sand" without loss of strength; some of the weaker ones may not be able to take more than half their weight of standard sand, while others can be mixed with considerably more than their own weight without loss of strength at the end of one year after mixing. All have a certain limit within which they may be made stronger by an admixture of good sand than they would be if mixed neat.

Cement mixed with sand always hardens more slowly than neat cement, and requires a much longer time to attain its maximum strength. As the proportion of sand to cement is increased, both the rate of hardening and final strength are diminished. Within certain limits, however, the strength of mortar increases over a longer period of time as the proportion of sand becomes greater and as the time of observation is extended the loss of strength due to larger proportions of sand becomes less. Thus a good Portland cement in a mortar containing 1 part sand to 1 of cement at the end of a year may be expected to be stronger than mortar of neat cement. At the end of three years the 1 to 1 mortar should be much stronger, while a 2 to 1 may be as strong as the neat mortar. At the end of four or five years the 2 to 1 mortar may be on even terms with the 1 to 1, while a 3 to 1 mortar may have steadily gained to perhaps three fourths the strength of the others, where it probably stops. Beyond the limit where the quantity of cement is sufficient to fill all the interstices in the sand the ultimate strength diminishes very rapidly as the proportion of sand increases.

Clean and sharp sand usually gives a higher strength

in mortar than that containing an admixture of clay or earth, or that composed of rounded grains. Coarse sand also usually gives greater strength than that which is very fine. It is often difficult, however, to judge of the quality of sand without experimenting with it. In some cases a small amount of fine clay does not appear to injure the strength of the mortar, while a judicious mixture in the sand of grains of various sizes may be of benefit through reducing the volume of interstices.

A mortar composed of sand and cement usually possesses greater ability to adhere to other surfaces when coarse sand is used than if the sand be fine.

ART. 24. WATER USED IN GAUGING.

The quantity of water used in mixing the mortar is one of the most important conditions; the less the quantity, provided there be sufficient to thoroughly dampen the mass of cement, the quicker will be the set. With some Portland cements, changing the quantity of water used in mixing neat cement from 20 per cent to 25 per cent of the weight of cement doubles or even triples the time required for the mortar to set. In other cases the effect is comparatively slight.

When the quantity of water used in mixing is sufficient to reduce the mortar to a soft condition the hardening as well as the setting becomes more slow, and the strength during the early period is less than if a less quantity be used. This difference disappears to some extent with time, and the mortar mixed wet may eventually gain nearly as much strength as though mixed with less water.

When the quantity of water employed is not sufficient

to reduce the mass to a plastic condition, the mortar will not be so thoroughly compacted and will not reach the same strength as when made plastic, unless pressure be applied to it. But if just sufficient water be used to thoroughly dampen the mortar, and pressure be applied to expel the air and close the voids, the early strength will be greater than when more water is used. This difference, like the former one, disappears to a certain extent with time, but the final strength is usually greater with the less quantity of water.

According to Prof. Le Chatelier, the solidity of the crystalline mass varies with the form, dimensions, and mode of aggregation of the crystals. In general, the strength of a single crystal is greater than its adherence to neighboring crystals. Long needle-like crystals give greatest strength, and crystals have this character more as the solution is more strongly supersaturated.

The nature of the water used in mixing may also affect the rate of setting. When sea-water is used the setting is usually slower than with fresh water, the chloride and sulphate of magnesia being the principal retarding elements. Cements with a high hydraulic index show a less difference between fresh and sea water than those of low index, and well-burned cements less than imperfectly burned ones. The experiments of M. Candlot indicate that this is due to the action of the salts mentioned above upon the aluminate of calcium and that those cements containing the highest percentage of aluminate are affected the most by being mixed with sea-water.

Water containing sulphate of lime in solution retards setting (see Art. 21).

Mortar kept immersed in sea-water usually hardens more rapidly than that kept in fresh water. This difference is commonly much more noticeable with neat cement than with mortar containing considerable proportions of sand. The strength gained in sea-water, however, although gained much more quickly, is generally less in final amount than that in fresh water. There is, however, a very great difference between various cements in this particular.

Cements with a low hydraulic index show the greatest difference between sea and fresh water. Those containing small quantities of free lime give much greater early strength in sea than in fresh water, but are also sooner disintegrated by the action of sea-water.

ART. 25. EFFECT OF ENVIRONMENT.

Cement mortar kept under water ordinarily hardens more rapidly in the early period than that exposed to the air, but usually that kept in air ultimately reaches greater strength. The highest strength is commonly produced by keeping the cement for a time in water, and later placing in dry air. Nearly any cement mortar will harden more rapidly and attain greater strength if kept moist during the operation of setting and the first period of hardening than if it be exposed at that time to dry air. A sudden drying out about the time of completing the set usually causes a considerable loss of strength in mortar, and frequently the mortar so treated is filled with drying cracks. This result is usually more marked when the cement is mixed with a large quantity of water to a soft condition.

The nature of the water in which the mortar is allowed to harden is of more importance to its strength than that of the water used in gauging. When the mortar is to be kept in air, the nature of the water used in mixing becomes more important, although probably the variations in ordinary natural water are rarely sufficient to produce any appreciable difference in the strength of the mortar. Mortars gauged with sea-water harden best in air.

ART. 26. EFFECT OF TEMPERATURE.

The temperature of the water used in mixing has an important bearing upon the time required for setting; the higher the temperature, within certain limits, the more rapid the set. Many cements which require several hours to set when mixed with water at a temperature of 40° Fahr. will set in a few minutes if the temperature of the water be increased to 80° Fahr. Below a certain inferior limit, ordinarily from 30° to 40° Fahr., the mortar sets with extreme slowness or not at all, while at a certain upper limit, in some cements between 100° and 140° Fahr., a change is suddenly made from a very rapid to a very slow rate, which then gradually decreases as the temperature increases, until practically the mortar will not set.

The temperature of the cement and that of the air in which the mortar is placed during setting influence the rate of setting in about the same manner as that of the water. In case the air in which the mortar is placed be dry, the setting will usually be somewhat more rapid than if it be moist; and if it be too dry, the rapid

evaporation of the water from the surface of the mortar may cause drying cracks in the mortar.

Quick-setting cements usually show a rise in temperature during setting, due to the rapidity of the action which takes place. It has been suggested that the time occupied by the setting would be better shown by observing the period of advanced temperature than by noting the stiffening of the mortar, as is common. Most slow-setting cements, however, do not show sufficient change of temperature, if any takes place, to be appreciable; and the rise in temperature, where it does take place, may not always be the result of the process of setting.

If the air at the time of mixing mortar be sufficiently cold to freeze the mortar before it can set, it will not set while frozen; but most cements will do so after thawing out, and but few of them will be injured by such freezing in so far as their ultimate strength is concerned. Recent experiments * have, however, seemed to show that mortar may set while frozen if it remains in that condition for a sufficient length of time.

The temperature of the water with which cement mortar is mixed has a quite appreciable effect both upon its rate of hardening and its ultimate strength, and the temperature of the air at the time of mixing has a similar effect. The lower the temperature at which the mixing is done, the slower the hardening and the greater the final strength. This difference is not sufficient to be important at ordinary air temperatures in so far as the use of mortar is concerned, but is quite appreciable in making comparative tests.

* Paper by Cecil B. Smith: Trans. Canadian Soc. C. E.

The temperature of the air or water in which the mortar is immersed during the time of hardening has a very appreciable effect upon the rate of hardening of many cements. This effect differs very radically for different material; with some the process is greatly accelerated by keeping them hot as compared with what would be the result in cold air or water; others are not appreciably affected, while still others seem to be retarded in their hardening by the application of heat. This variation is to be found among cements of the same class, and is seemingly independent of their value. Cements of low hydraulic index usually show the greatest gain in rate of hardening under the action of heat.

Art. 27. Effect of Age upon Cement.

The effect upon a cement of retaining it a long time before using depends upon the nature of the cement and the method of keeping. When the cement is enclosed so as to prevent the access of air, as in barrels, it may usually be preserved for a considerable time without experiencing any alteration, provided it is kept dry.

When exposed to the air the cement commonly undergoes more or less alteration. Portland cements of good quality are usually but slightly affected, as they are composed for the most part of stable compounds. The change which occurs is limited usually to making the cement slower-setting. Where the cement is originally slow-setting this effect may be very slight, and the cement may perhaps be retained for a long period, two or three years at least, without appreciable change in its properties. A hard-burned cement, originally quick-setting,

usually becomes slower-setting with age, but commonly without injury as to its ability to harden and its ultimate strength.

Light-burned cements, particularly Roman cements, are affected in much greater degree by age. These cements not only become slower-setting when exposed to the air, but commonly also they gradually lose the power of hardening and become finally inert—in many cases becoming puzzolanic material, the activity of which may be restored by the addition of slaked lime.

The changes which occur in cements kept in dry air are attributed to the action of carbonic acid upon the free lime which they may contain, and perhaps also upon the less stable compounds, as the aluminates of lime, which contribute to the rapid set and are found most plentifully in the light-burned material.

Art. 28. Effect of Fineness.

The degree of fineness to which the cement is ground is always very important in its effect upon the strength of mortar made from the cement. The valuable part of the cement is practically only that portion which is ground extremely fine—to an impalpable powder. The coarse parts are not altogether inert, but are more or less active, depending upon the size of the grains of which they are composed. As the clinker obtained in burning cement is very dense and hard, it is ground with difficulty, and the coarser particles are apt to be of the best burned, and therefore most valuable, part of the material. Coarse grinding is likely therefore to leave

in a useless condition much of what should be the most active portion of the cement.

The rate of setting is accelerated as the fineness to which the cement is ground becomes greater. In a finely ground cement the amount of active material is greater than in one coarsely ground, and the chemical reactions which take place in setting are facilitated by fine subdivision of the particles. When the cement is gauged with sea-water the rate of setting is less influenced by the fineness.

The hardening of cement mixed neat is not greatly affected by fineness; that finely ground usually hardens more rapidly, but attains less final strength than when more coarsely ground. The hardening of the coarsely ground cements is more gradual and regular and the ultimate strength greater.

Cement, when used, is commonly mixed with sand, and the attainment of strength in sand mortar rather than mortar of neat cement is therefore of importance. The finer ground the cement the greater its resistance when mixed with sand, both in the earlier and later stages, and also the sooner will it reach its ultimate strength. The effect of fine grinding is much greater when the proportion of sand to cement is large, as the power of the cement to take sand without diminution of strength is thereby greatly increased. The coarser particles of the cement may be considered as practically inert material, which acts rather as sand than as cement in the mortar, and the power of the cement to harden and develop strength in sand mortar is thus dependent upon the amount of fine material contained in it.

The adhesive strength of cement increases very rapidly

with the fineness, at least in the early period of hardening.

The difference between coarse and fine grinding is greater in the early period of hardening than later. The fine cement hardens much more rapidly, but the coarse cement, especially in rich mortar, often reaches nearly the same ultimate strength. The attainment of extreme fineness may not therefore always be economical when the extra cost is considered.

CHAPTER IV.

THE SOUNDNESS OF CEMENT.

ART. 29. PERMANENCE OF VOLUME.

THE permanence of any structure erected by the use of cement is dependent upon the power of the cement, after the setting and hardening processes are complete, to retain its strength and form unimpaired for an indefinite period. Experiment has shown that mortars made from cement of good quality frequently continue to gain in strength and hardness through a period of several years, or at least that there is no material diminution of strength with time; and that changes of temperature, or in the degree of moisture surrounding it, produce no injurious effects upon the material. This durability in use is commonly known as the *permanence of volume* or *soundness* of the cement.

Heat has the same effect in causing expansion or contraction of cement mortar that it has upon other materials. The coefficient of expansion for neat Portland cement, according to a series of experiments at "l'école des Ponts et Chaussées," is about the same as that of iron. For sand mortar the coefficient is somewhat less.

When mortar which has been immersed in water is transferred to dry air a slight contraction may take place

in volume, together with an increase in strength, while a transference the other way may produce the opposite result; but no distortion of form or disintegration of the mortar will take place in either case if the cement be of good quality.

Sometimes cement when made into mortar sets and hardens properly, and later, when exposed to the action of the atmosphere or water, becomes distorted and cracked, or even entirely disintegrated. If the composition deviates but slightly from the normal this process of disintegration may not show itself for a considerable time, and proceeds very slowly. It thus becomes an element of considerable danger, as it is liable to escape detection in testing the cement.

The unsoundness of cement may be occasioned either by defective composition, causing the mortar to yield to the action of expansions proceeding from within itself, or by exterior agencies which act upon ingredients of the cement susceptible to their influence, or are permitted to act by the method of making and using the mortar. Very little is definitely known concerning these various destructive agencies, and there is considerable doubt concerning the causes which operate in many instances. The expansive action is commonly attributed to free lime or magnesia. The exterior agencies are the action of frost, of dry air and heat, and of sea-water.

Most cements probably contain small amounts of the expansive elements, which when in small quantity act with extreme slowness and perhaps produce no visible effect for several months after the use of the mortar; then there occurs a decrease of strength, which probably disappears with time. Cements of low index,

which gain strength very rapidly in the early period, are quite apt to act in this manner, and occasionally, as already noted, the cement may not possess sufficient strength to resist, and the expansive action continues to ultimate disintegration.

The term *Permanence of Volume,* if limited to the power of the material to resist actual change of form or dimension in the body of mortar, is not necessarily synonymous with *soundness,* if by soundness we designate its power to resist disintegration over a long period. Most unsound cements fail by swelling and cracking under the action of expansives. In some cements, however, the failure occurs by a gradual softening of the mass of mortar, without appreciable change of form or dimension, the process being very slow, sometimes not noticeable for several months after the mortar is mixed.

Art. 30. Free Lime.

The presence of small quantities of free lime in the cement is doubtless one of the most frequent causes of disintegration in cement mortar. The lime being distributed through the cement in small particles is hydrated very slowly after the setting of the cement, causing, through its swelling during slaking, a strong expansive force on the interior of the mortar, and producing an increase in volume, loss of strength, and perhaps final disintegration.

The effect of the lime depends upon its physical condition and is affected by the degree of burning.

Lime burned at a high heat slakes much more slowly, and is therefore more likely to be injurious than when

burned at a low temperature. Prof. Le Chatelier found that where the addition of quicklime formed by burning the carbonate produced no result, that obtained from the nitrate caused swelling and cracking in the mortar. The presence of free lime in hard-burned cements of low index is therefore of special importance and must be carefully guarded against by securing accurate composition and complete reactions in burning.

The fineness of the cement also modifies the action of the free lime, as finely divided material will slake quicker than coarse grains, and the lime is more apt to become hydrated before setting is completed; or if the cement be exposed to the air before use, the lime in a fine state will sooner become air-slaked.

If free lime be present in such condition that it becomes slaked before the initial set of the cement, it causes no injury. If it becomes slaked during the setting or first period of hardening, the strength of the mortar may be reduced, being rendered less compact and more porous. In case this action be not sufficient to cause disintegration the loss of strength may to a great extent subsequently disappear.

When the slaking of the free lime does not take place until a longer period of time has elapsed, the danger in the use of the cement is more serious. When the expansive action becomes sufficient to overcome the tenacity of the mortar, disintegration ensues. If the expansive action be not sufficient to overcome the tenacity of the mortar, an increase in volume and loss of strength in the mortar may take place, the extent of which is dependent upon the relative intensities of the expansive and resisting forces.

These effects may afterward gradually disappear, but they probably have the effect of making the mortar more easily attacked by external agencies. Cement of low hydraulic index, which gain strength rapidly in the early period of hardening, are particularly liable to contain appreciable quantities of free lime, which is frequently shown by a loss of strength when tests are extended over a considerable period of time.

Mortar kept under water is acted upon much more rapidly than that exposed to dry air.

ART. 31. MAGNESIA.

Free magnesia in cement acts very much like free lime. The action of magnesia, however, is much slower than that of lime, and for this reason it is a more serious defect, because less likely to be detected in the tests applied before using. Prof. Le Chatelier mixed 5 per cent of lime and of magnesia with two samples of Portland cement, and observed the time required for the swelling to begin, resulting as follows:

	Swelling at 0° C.		Swelling in Water at 100° C.	
	Commenced.	Ended.	Commenced.	Ended.
5% lime......	in 3 hours	36 hours	immediately	in ½ hour
5% magnesia.	in 6 months	....	6 hours	40 hours

In hard-burned cements of low hydraulic index any magnesia which may be present is likely to be in a free state, and hence the percentage of magnesia in such material should be low, and specifications frequently

limit the amount of magnesia that may be allowed in Portland cement.

When mortar fails from this cause the expansive action may not be shown for several months after the mortar has set, and then in a comparatively short time the swelling, cracking, and disintegration take place.

Dr. Erdmenger made a large number of experiments upon the effect of adding small quantities of magnesia to Portland cement, and found * that all expanded in water and contracted in air; those containing considerable percentages disintegrated, beginning after about 90 weeks.

The fineness of the grains of magnesia, like those of lime, is important as affecting the intensity of the effect. Prof. Le Chatelier found that where magnesia coarsely ground produced swelling and cracking, the same quantity of finely ground magnesia produced swelling, but without distorting or cracking the mortar. The extent of the change in volume varies with the quantity of magnesia, increasing rapidly as the quantity is increased.

The expansion is reduced as the mortar is mixed more wet, being less as the porosity of the mortar is greater.

In light-burned cements the danger of free magnesia is greatly lessened, and many good cements of this class contain large percentages of magnesia. An overdose may, however, be an element of danger in any case, and several failures of mortar in Europe have been attributed to magnesia in both hard-burned and light-burned cements.

M. Durand-Claye gives an instance † where the cement

* Journal Society of Chemical Industry, vol. XII, p. 927.

† Annales des Ponts et Chaussées, 1886, vol. I, p. 845.

in a work swelled and cracked, and an examination showed that it contained 16 to 28 per cent of magnesia. Experiments were made by mixing magnesia with good cement, and swelling resulted. The rock which served for the manufacture of the cement contained a large proportion of magnesia, which was probably present in an uncombined state in the cement. The time in which the swelling occurred was found to depend upon the amount of water available. When mixed with the normal quantity and left in dry air no expansion took place. It is therefore only dangerous in water.

Analyses of this cement are given as follows:

Silicious Sand.	Silica. %	Alumina. %	Iron. %	Lime. %	Magnesia. %	Sulphur. %	Loss on Ignition.
....	14.80	8.00	4.60	47.30	24.30	0.60	0.40
....	18.30	2.95	3.60	44.80	28.15	2.30	1.90
0.35	20.70	3.35	3.65	43.30	26.70	0.15	1.80

This is not similar to the magnesian cements commonly used in the United States on account of the extremely low hydraulic index. If it be assumed that in the normal cements of this class the magnesia acts like lime in combining with silica and alumina, the presence of free magnesia might be accounted for by the lack of a sufficient quantity of these hydraulic elements.

The silicates and aluminates of magnesia are known to possess, like those of lime, the property of hardening under water. Their action, however, is said to be much slower than that of the lime salts, and it has been suggested that the presence of the magnesian salts might be sometimes injurious on account of their hydrating after the hardening of the lime salts in the cement. It has

not been shown, however, that any swelling takes place in the setting of these salts, and the effect may be to contribute to the final strength. Whatever the nature of the process, it is certain that some good magnesian cements continue to increase in strength over a long period, the proportionate increase in the later period being much greater than for Portland cement of even very moderate action.

Art. 32. Aluminate of Lime.

The exact rôle of aluminate of lime is in many cases a matter of considerable doubt. M. Bonnami considers the basic aluminates to act as expansives in hydrating like lime, being decomposed in presence of water. The action of water upon these aluminates is very rapid, heat being given off, with the result of greatly accelerating the set of cements containing them in appreciable quantities.

The disintegration of mortar has in certain instances been attributed to the hydration of aluminates subsequent to the set. It seems probable, however, that where the aluminate is present in small quantities that its hydration usually takes place before the setting of the cement, and in fact is the first cause of the setting action.

Aluminate of lime is freely acted upon by calcium sulphate, as stated in Art. 21, forming the sulpho-aluminate ($3CaO.Al_2O_3+2.5SO_4Ca+60H_2O$), which crystallizes with great expansive force. When a cement containing aluminate is exposed after setting to water containing calcium sulphate the combination of the sulphate

with the aluminate may take place, with the result of causing swelling and, if sufficient in quantity, disintegration of the mortar.

Aluminates should therefore be avoided in cements to be used for mortar to be exposed to the action of sea-water, as the sulphate of magnesia acts upon the lime of the cement, forming the sulphate of lime, which then combines with the aluminate of lime, producing the expansive action. For this reason cements high in alumina are not considered desirable for marine work.

ART. 33. SULPHUR COMPOUNDS.

The action of sulphur in cement is extremely variable, depending upon the state in which it may exist and the nature of the cement. The effect of adding sulphate of lime for the purpose of rendering the setting slower has already been discussed (Art. 21). This action depends upon the presence of aluminate of lime in sufficient quantity to take all of the sulphur into combination. When the sulphate is added in excess, or to a cement without the aluminate, it remains soluble in the mortar and is gradually dissolved out, having only the tendency to make the mortar porous.

It is pointed out by M. Candlot that if the aluminate be prevented from acting by adding slaked lime to a cement with which sulphate of lime has been mixed, the combination of the sulphate and aluminate may take place after setting, causing the destruction of the mortar through its expansive action.

The effect of the existence of sulphate in the material before burning the cement may be quite different from

that of adding it afterward. In Roman cement the two seem to give analogous results; but in the heavily burned cements it may be in a state not readily soluble, and hence slow in acting upon the aluminate, thus causing the expansion to be delayed until after the set.

Mr. Spachman, who experimented upon the production of Portland cement from alkali waste, concludes * that the danger in using material containing too large proportions of sulphate of lime is due to the likelihood of forming calcium sulphide, CaS, during the burning, which afterward forms, with the iron oxide of the cement, the sulphide of iron, FeS. This upon exposure is oxidized to a sulphate of iron, changing the color of the cement to a brown, and causing it to lose much of its activity, in some instances scarcely setting at all. Mr. Spachman gives the limit of about 5% of SO_4Ca as what may be safely used.

Prof. Tetmajer states that calcium sulphate in Portland cement sometimes acts as an expansive through the fact that it is readily oxidizable and expands in oxidation.

In slag cements the presence of calcium sulphide is thought to be less injurious. According to M. Prost it gives a green color to the cement when kept in water, but without injury to its strength. In the air it may cause the mortar to crack.

---

* Journal Society of Chemical Industry, vol. XI, p. 497.

Art. 34. Exterior Agencies.

The principal exterior agencies which operate to cause the destruction of mortar are changes in temperature or in humidity and the nature of the water with which it may be in contact. Exterior mechanical agencies, such as the shocks of waves or of ice and sand produced by a current, have an abrasive action and may oxertax the strength of mortar in the early period of hardening, but they do not cause disintegration through injury to the cement.

The effect of frost is to set up a mechanical action through the freezing of water in the pores of the mortar and resistance to it probably depends mainly upon the strength of the mortar and its ability to resist this expansion.

The nature of the water to which the mortar is exposed is important because of the possible chemical action of salts which it may hold in solution. This is shown by the disintegration of mortar in sea-water or in sewer-water which is quite sound when subjected to fresh water.

According to M. Candlot, "all hydraulic materials are alterable by pure water. A mortar traversed by pure water finally loses all coherence, the elements constituting the agglomerant being little by little decomposed. But natural water contains always carbonic acid, which intervenes in the majority of cases to arrest decomposition and close the pores of the mortar traversed by the water. When the cement does not give up its lime too readily the lime is transformed into carbonate,

which forms a deposit in the voids of the mortar. If, on the contrary, the dissolving of the lime in the water which traverses the mortar is abundant, there is produced a large quantity of carbonate without cohesion, which is carried off by the water."

In regard to the effect of temperature Prof. Le Chatelier says: "At elevated temperatures certain solid hydrates lose their water and are reduced to powder, like the crystalline carbonate of soda, and cause the disintegration of the mortar. This is the case with certain aluminates of lime, especially the alumina-sulphate, but precise experiments are still necessary upon this subject.

"This dehydration occurs in dry air. This explains the well-known fact that certain cements stay for months in water and attain high strength, but the same exposed to dry hot air disintegrate into a sandy mass."

M. Candlot says that "aluminous cements are subject to alteration in surroundings exposed to alternate dryness and humidity, and also when exposed to a high temperature." It should be remarked, however, that this probably depends upon the alumina being present as basic aluminate of lime, and that cements with a high proportion of alumina, such as certain Roman cements, containing considerable sulphate, commonly give good results when used in situations exposed to changes in humidity. The Louisville cements are a prominent example of this.

When cement mortar during the earily period of hardening is exposed to very dry air, the hardening may be interfered with by the lack of moisture necessary to admit of the completion of the hydration and crystallization of the cement, thus causing a lack of cohesive strength

and perhaps ultimate destruction of the mortar. Different cements vary greatly in the extent to which they are influenced by this cause, slow-setting Portland cements being ordinarily least and the slag cements most affected.

ART. 35. EFFECT OF SEA-WATER.

The destructive effect of sea-water upon hydraulic mortars which are sound in fresh water is probably due to the action of magnesium salts upon the lime of the cement, thus forming sulphate and chloride of calcium. The action of these salts upon the hardening of cement mortars has already been discussed.

When mortar in sea-water fails by swelling, the failure is usually attributed either to too large a proportion of free lime or magnesia, or to aluminate of lime in the cement. When the cement contains free lime, the expansive action is greatly intensified in sea-water as compared with that in fresh water. This may be explained by the presence of calcium chloride, which increases the rapidity of slaking of quicklime, causing the expansion to be shown sooner, and to act more violently than in fresh water. When the cement contains considerable aluminate of lime the calcium sulphate may act upon it, as indicated in Art. 32, causing the formation of the sulpho-aluminate and the corresponding expansive effect.

When mortar made from cement of good quality is exposed to the action of sea-water its durability depends largely upon the permeability of the mortar. The lime salts formed by the action of sea-water are readily soluble, and if the mass is freely permeated by water those

salts may be washed out, leaving the mortar more open to the action of the disintegrating agencies. Thus mortar of any Portland cement may be injuriously affected by sea-water if used in such manner as to permit the continuous action of the magnesian salts through the mass.

The ultimate hardening of mortar in sea-water, as in fresh water, seems to depend upon the action of carbonic acid in forming a protection to prevent the operation of the elements of disintegration. When the mortar resists the penetration of the water so as to prevent its renewal in the interior of the mass, the outside soon becomes protected by the action of the carbonic acid and effectually prevents further action of the magnesian salts.

M. Durand-Claye examined the mortar from a sea-wall where parts of it were disintegrated and found a large proportion of magnesia, although it was not contained in the original mortar or in the portions of the wall which were still sound. The percentage of sulphuric acid was also increased in the disintegrated portions, seeming to show that the magnesia had been precipitated from the sulphate of the sea-water, and the resulting sulphate of lime had for the most part washed out.

Where the water against the wall is under pressure from one side, or where tidal flow keeps the work submerged only a part of the time, the action of the sea-water is more strongly felt than in work always entirely covered.

M. Alexander submitted blocks of cement mortar to the filtration of both fresh and sea-water.* Those in

* Annales des Ponts et Chaussées, 1890, vol. 1, p. 408.

fresh water were unaffected, but those in sea-water were disintegrated in six months. Analysis showed that those in fresh water suffered a slight loss of lime and sulphuric acid, while those in sea-water were much changed by loss of lime and gain in magnesia and sulphuric acid.

M. Alexandre also found that "argillaceous or soft calcareous sand is attacked by sea-water, and mortar containing them may be decomposed although the cement is good."

CHAPTER V.

METHODS OF TESTING CEMENT.

ART. 36. OBJECT OF TESTS.

TESTS of cement may have for their object either the examination of the quality of the material in order to determine its fitness for use or investigation of the properties of the cement for the purpose of increasing knowledge of its behavior under the varying contingencies of use. Where experiments are made with this latter object, the tests to be applied and methods of operation must of course be dependent upon the special point to be investigated.

In many instances it may be possible to combine to a certain extent the two objects. This is particularly the case where a permanent laboratory is established to regulate the reception of material for extensive works, as in the case of the laboratories connected with the Government experiment stations in Europe. In some of these stations careful examination of every sample of cement in a number of particulars is made, with the result of accumulating a mass of valuable information regarding the characteristics of all the different kinds of cement. Systematic series of tests of this character possess much greater value as a means of deducing the

laws governing the action of the mortar than special examinations upon particular points, which often fail to take into account the variable nature of the material and the necessity for exact knowledge of the nature of the cement upon which the tests are made.

The French Commission upon the Method of Testing the Materials of Construction recommend that in the permanent laboratories cement should be systematically tested in the following particulars: Chemical analyses; fineness; specific gravity; apparent density; homogeneity; time of setting; tensile, compressive, flexural, and adhesive strength; permanence of volume; porosity; permeability; resistance to decomposition by sea-water; and yield of mortar.

Tests of cement, as commonly made for its reception upon engineering work, have for their object only the determination of the quality of the material and its fitness for the use. Tests for this purpose must be made according to some recognized standard, and cannot closely approximate the conditions of use without impairing their value as means of judging the quality of the cement. What it is necessary to know about the cement is that it will set and harden into a solid mass, which will firmly adhere to any surface with which it may be in contact, and that it will endure through a long time without change of form or loss of solidity.

As ordinary tests must be made in a short time, but a few days at most being usually allowed for determining the quality of the material, the problem to be met in testing is to apply such tests as will enable a prediction to be made, from its behavior under them in a short time, as to what it will do in a long time under the cir-

cumstances of its use. The difficulty of this with a material varying so greatly in character and in its behavior under various conditions is evident. Having a particular brand of cement whose characteristics are known, it may readily be determined whether a given sample is of normal quality, and something may be predicted of its future from its behavior under short-time tests. Very little, however, can be done in the way of generalization, and for a new and unknown material it is only possible to state a somewhat indefinite probability as to final results.

Tests may be imposed which in nearly all cases will secure good material, but often at the expense of rejecting equally good or better material. This, however, will be unavoidable until the characteristics of the various brands of cement are more fully known and the tests to which each should be subjected better understood.

The tests which are usually imposed to determine the quality of hydraulic cement are those of weight, fineness, time of setting, tensile strength, and soundness. Chemical analysis is sometimes made, and specific-gravity test is substituted for that of weight, or both are frequently omitted. Compression tests are also sometimes added.

The greatest weight is usually given to the test of tensile strength, and much greater value is commonly placed upon the results of that test than they deserve. It is much the simplest and best means of making a test for strength, and is very desirable as showing the proper hardening of the mortar, but cements cannot be graded in value by the strength attained in a short time. Cement giving high early strength is to be relied upon only

in so far as it has been shown by experience capable of subsequently maintaining such strength. The attempt to produce cement which will develop great strength on short-time tests is liable to result in lowering the hydraulic index, or the addition of calcium sulphate, and sometimes in the presence of free lime, giving a material more likely to be unsound than one of more moderate strength.

The test for soundness or permanence of volume is an important one, as giving an indication of the probable durability of the material; but in this, as in the other tests, a knowledge of the usual action of the material will contribute greatly to the proper interpretation of the test.

The test for fineness is also important as bearing upon the power of the cement to take sand.

It was recommended by the committee of the American Society of Civil Engineers upon a uniform system of testing, that tests for quality be limited to the above three most important tests—fineness, tensile strength, and soundness; and this recommendation is now commonly followed in the United States, although the test for soundness as usually made is of little value.

Art. 37. Apparent Density.

The *apparent density* of cement is measured by determining the weight of a given volume of the material. This test is made as a means of showing whether the process of manufacture has been well conducted. If the cement be not thoroughly burned, or if it lack homogeneity so that in portions of it the combinations are not complete, the weight is less than when the material is homogeneous

and well burned. Variations of composition also affect the weight, so that there may be considerable variations in the weight of various cements of good quality, equally well burned.

The apparent density is affected by the fineness to which the cement is ground; the coarser the particles of the cement the greater its weight per unit volume. The weight test when employed should therefore be combined with one for fineness to prevent the attainment of heavy weight by coarse grinding.

The test for apparent density is not usually employed for the reception of material, as it is somewhat indefinite in result. It is, however, sometimes included in specifications in England, and is used in many European laboratories where a careful study is made of the properties of cement.

As the cement powder may be packed in the measure so as to give very different weights for the same volume, it is necessary to use a uniform method of filling the measure in determining the weight. The common method of conducting the test is to pass the powder through a sieve and allow it to fall through a funnel or down an inclined plane through a given height into a measure, which when full is struck and weighed. The height of fall and the size of the measure both affect the result, the cement packing closer in a large than in a small measure.

In Europe several appliances are used for testing apparent density.

Tetmajer's Apparatus.—The apparatus of Prof. Tetmajer is used in a number of the leading laboratories. It is shown in Fig. 1, and consists essentially of a cylindrical

measure (*M*) of 1 litre capacity and 10 centimeters high, provided with ears which catch upon a frame formed of two levers (*L*). The frame is raised and dropped at each turn of the hand-wheel by the cam (*O*), thus giving a succession of jars to the measure.

Above the measure a sieve (*R*) is oscillated upon a system of levers which are hinged to the base, and moved by the rod (*V*), giving two oscillations at each turn of

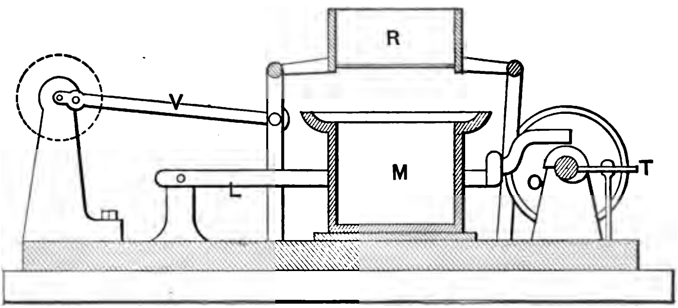

FIG. 1.

the hand-wheel. The number of revolutions is recorded by the revolution-counter (*T*).

In the operation of the apparatus the cement is filled into the sieve and shaken through by the oscillations produced by turning the hand-wheel. It is caught in the measure and jarred down by the raising and dropping of the frame. About 500 revolutions are necessary to secure the best results in compacting the powder in the measure. The compactness is found to vary with the rapidity of motion, a moderate speed of about 200 revolutions per minute giving a maximum effect and being considered most desirable.

Inclined-plane Apparatus.—The inclined-plane apparatus for apparent density has been used in a number of forms, one of which, employed in France and recommended by the Commission des Méthodes d'Essai des Matériaux de Construction, is represented in Fig. 2.

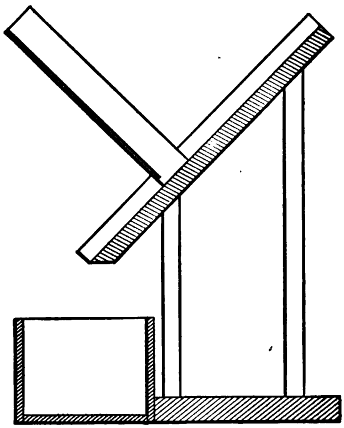

FIG. 2.

The inclined plane is formed of sheet zinc 30 cm. long and inclined at 45° with the horizontal. It is 10 cm. wide for the upper two thirds of its length, and through the lower third diminishes gradually to 5 cm. at the lower end. The zinc is turned up at the sides to form a channel in which the material may slide.

At the point where the larger plane begins to narrow a second sheet of zinc, 20 cm. long and 10 cm. wide, is set at right angles to the first, leaving an opening of 1 cm. The measure 10 cm. high and of 1 litre capacity is placed with its top 5 cm. below the lower edge of the plane.

The cement is poured in small quantities on the summit of the secondary plane so slowly as not to clog the opening between the planes, until the measure is full when it is struck and weighed.

A single inclined plane of somewhat greater length (50 cm.) is sometimes used, the cement being sifted upon the upper end and allowed to slide directly into the measure. It is said, however, to give less uniform results than the double plane unless handled with extreme care.

German Funnel Apparatus.—This apparatus was recommended by the German conference upon methods of testing materials, as was also the Tetmajer apparatus.

The funnel is formed of a hollow cone with its axis vertical, as shown in Fig. 3. The height of the cone is 18 cm., its upper base is 20 cm. and lower base 2 cm. in diameter, terminated at the lower end by a second cone 5 cm. high, with a lower base 1.6 cm. in diameter. The funnel is supported upon a tripod, with its lower end 20 cm. above the table and 10 cm. above the top of the litre measure. To facilitate the flow of cement into the measure a rod 7/10 cm. in diameter is rotated in the axis of the funnel. This rod is guided by two cross-rods supported upon the interior surface of the funnel.

In the operation of this apparatus sufficient cement to fill the measure is placed in the funnel and the rod is then rotated, about 45 revolutions per minute, by gear or by hand until the material has passed through and filled the measure, which is then struck and weighed.

Sieve and Funnel Apparatus.—This apparatus as used in France is shown in Fig. 4. It consists of a funnel

with a sieve fitting into the upper part of it and the measure below. The cement is put into the sieve and gradually worked through by the use of a spatula. It then slides down the funnel into the measure until that is filled.

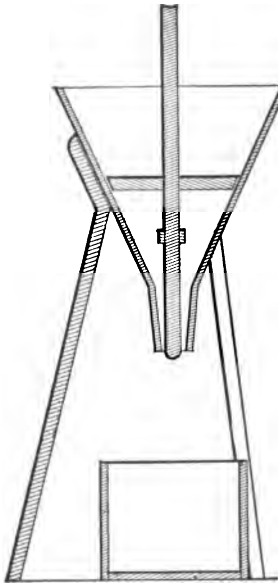

FIG. 3.

The Commission des Méthodes d'Essai des Matériaux de Construction made a careful comparison of results obtained by the various methods. They found the German funnel apparatus quite precise in its results with certain materials, but that with some cement it always became clogged by the packing of the material in the funnel. The Tetmajer apparatus is capable of great precision, but is somewhat complicated, and

requires careful manipulation to secure always the same rate of filling the measure and the same amount of compacting. The inclined plane and the sieve and funnel apparatus are found to give good results, and are recommended by the commission for use in France in

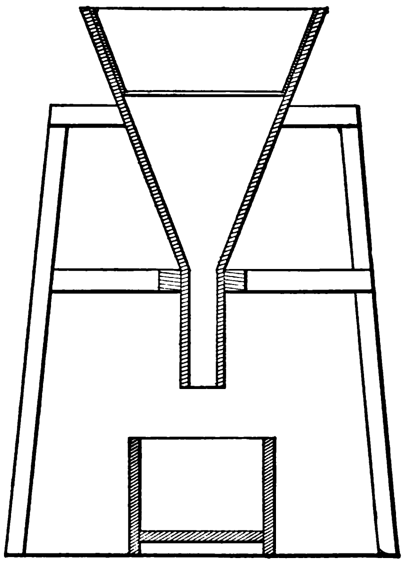

FIG. 4.

their report of 1895. The two latter give nearly identical results, the German apparatus somewhat higher and the Tetmajer apparatus much larger results than the others.

In making tests for apparent density it is common to sift the cement and use only that portion which passes the finest sieve, thus including in the test only the fine powder which is supposed to be the active portion of the cement and eliminating to a certain extent the in-

creased weight which would otherwise follow coarse grinding. The coarse particles thus removed are the hardest burned and therefore heaviest portion of the cement. To accomplish this the sieve used should be as fine as possible in order to eliminate all but the impalpable powder. In Europe a sieve of 5000 meshes per square centimeter is employed for this purpose, corresponding to the No. 180 sieve, 32,400 meshes per square inch.

The Committee upon Cement Testing of the American Society of Civil Engineers, recommended, in 1885, a method of making weight tests for cement for use by American engineers. This test, however, never came into practical use and it is not customary in the United States to make any test of this character. The variation in results of such tests under ordinary manipulation is so great, and the results are so dependent upon the fineness of grinding that when a density test is desired the specific gravity is usually determined. A similar committee in 1904 recommended the specific gravity test only.

The ordinary weight of Portland cement varies from 70 to 100 lbs. per cubic foot, depending largely upon the method of making the tests. Natural cement is usually somewhat lighter.

Art. 38. Specific Gravity.

The determination of *specific gravity* is often substituted for that of apparent density, and is a much better guide to a knowledge of the actual density of the material, as it is not subject to the fluctuations due to fineness or

method of determination which characterize the weight tests. The differences of specific gravity to be determined are, however, very small, and great care is necessary in the manipulation of the test in order to obtain reliable results.

The test for specific gravity is commonly made by immersing a known weight of the cement in a liquid which will not act upon it, and obtaining its volume through noting the volume of liquid displaced. In making the test by this method it is necessary that all the air-bubbles contained in the cement powder be eliminated, and that the volume obtained be that of the cement particles only.

Schumann Volumenometer.—Several forms of apparatus have been used for this purpose. Of these the Schumann volumenometer, shown in Fig. 5, is perhaps the most common. It consists of a graduated tube the bottom of which is ground to fit closely into the top of a flask.

In the use of the apparatus the tube is placed upon the flask and filled with benzine to the zero-point on the scale; 100 grammes of cement are then weighed and carefully poured into the top of the tube so as to sift gradually through the liquid, thus allowing the air to escape.

The elevation of the surface of the liquid in the tube gives the volume of the cement. The scale as ordinarily made has a range of 40 cubic centimeters and is graduated to 1/10 centimeter. This volumenometer gives very satisfactory results when carefully used, but much care is required to fully eliminate the air and prevent the powder from adhering to the surface of the tube. It is well in operating in this manner to introduce the liquid

through a long funnel, thus keeping the inner surface of the tube dry.

In some instances greater accuracy may perhaps be obtained by filling the apparatus to the zero-point with

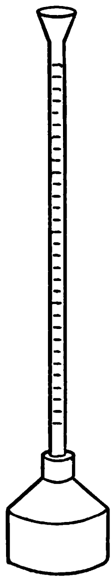

FIG. 5.

liquid and weighing the whole, then pouring in enough cement through a funnel to raise the surface of the liquid through a definite volume and determining the weight of cement by reweighing the whole. This eliminates the error due to loss of cement powder in introducing it into the flask.

Candlot's Volumenometer.—M. Candlot has modified the Schumann volumenometer by closing the upper end of the tube with a glass bulb. In using this form

of the apparatus the tube is turned bottom upward and the bulb filled with benzine. The flask is then placed upon the tube, the apparatus is inverted and a reading taken of the height reached upon the tube. A weighed quantity of cement is then placed in the tube, which is turned upside down and separated from the flask for the purpose. The flask being replaced and the whole again inverted, the volume is shown by the rise of the liquid in the tube. In order to eliminate the air-bubbles the apparatus is shaken before taking the second reading so as to thoroughly mix the liquid and the cement.

This method is much more rapid than that with the Schumann volumenometer, but in practice is hardly so satisfactory in result.

Le Chatelier's Volumenometer.—This apparatus is shown in Fig. 6. It consists of a flask the top of which is drawn out into a tube 1 cm. in diameter and 20 cm. long. Above the middle the tube enlarges into a bulb for a short space and then again continues with uniform diameter to the top. The flask to a point marked on the tube just below the bulb has a capacity of 100 cubic centimeters. From this point to a mark above the bulb the capacity is 20 cubic centimeters. This latter mark is very carefully determined, and the upper part of the tube is graduated to 1/10 cubic centimeter.

In using this apparatus, the flask is filled with liquid to the mark below the bulb, and the cement is then slowly introduced through a funnel and settles through the liquid into the flask, the air being eliminated by its long passage through the liquid. Cement is added until the surface of the liquid rises to the 20-cubic-centimeter mark. The weight of this volume of cement is obtained by

weighing the apparatus before and after the cement is introduced. Or, this volumenometer may be used in the same manner as that of Dr. Schumann, the bulb serving to prevent the cement sticking to the sides of the tube.

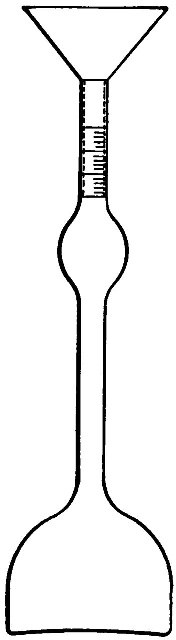

FIG. 6.

Changes in temperature of the liquid used may often affect its volume sufficiently to materially influence the results of this test, and it is important that the liquid should be maintained at a nearly uniform temperature during the test. For this reason it is common to immerse the apparatus in cool water. The liquids used are also

commonly somewhat volatile and the temperature should be kept low in order that the results of the test may not be affected by the evaporation losses. When benzine is used the temperature should not be above 60° Fahr.

The committee on Uniform Tests of Cement of the American Society of Civil Engineers (1904) recommend the use of the Le Chatelier apparatus and that the apparatus be submerged in water in a tall jar during the test.

The recommendation of the committee is as follows:

"*Significance.*—The specific gravity of cement is lowered by underburning, adulteration, and hydration, but the adulteration must be in considerable quantity to affect the results appreciably.

"Inasmuch as the differences in specific gravity are usually very small, great care must be exercised in making the determination.

"When properly made, this test affords a quick check for underburning or adulteration.

"*Apparatus and Method.*—The determination of specific gravity is most conveniently made with Le Chatelier's apparatus. This consists of a flask of 120 cu. cm. (7.32 cu. inches) capacity, the neck of which is about 20 cm. (7.87 inches) long; in the middle of this neck is a bulb, above and below which are two marks; the volume between these marks is 20 cu. cm. (1.22 cu. inches). The neck has a diameter of about 9 mm. (0.35 inch), and is graduated into tenths of cubic centimeters above the upper mark.

"Benzine (62° Baumé naphtha), or kerosene free from water, should be used in making the determination.

"The specific gravity can be determined in two ways:

"(1) The flask is filled with either of these liquids to

the lower mark and 64 grs. (2.25 ozs.) of powder, previously dried at 100° C. (212° F.) and cooled to the temperature of this liquid, is gradually introduced through the funnel (the stem of which extends into the flask to top of the bulb) until the upper mark is reached. The difference in weight between the cement remaining and the original quantity (64 grs.) is the weight which has displaced 20 cu. cm.

"(2) The whole quantity of the powder is introduced, and the level of the liquid rises to some division of the graduated neck. This reading plus 20 cu. cm. is the volume displaced by 64 gr. of the powder.

"The specific gravity is then obtained from the formula

$$\text{Specific gravity} = \frac{\text{Weight of cement}}{\text{Displaced volume}}.$$

"The flask, during the operation, is kept immersed in water in a jar, in order to avoid variations in the temperature of the liquid. The results should agree within 0.01.

"A convenient method for cleaning the apparatus is as follows: The flask is inverted over a large vessel, preferably a glass jar, and shaken vertically until the liquid starts to flow freely; it is then held still in a vertical position until empty; the remaining traces of cement can be removed in a similar manner by pouring into the flask a small quantity of clean liquid and repeating the operation.

"More accurate determinations may be made with the picnometer."

In order to make the determination of specific gravity of value, it must be reliable to two decimal places. Port

land cement varies from about 3.00 to 3.18, and is usually above 3.05. Natural cements vary from 2.75 to 3.10. An inferior limit is sometimes fixed in specifications—usually for Portland cement about 3.05 or 3.10, and for Roman cement about 2.80. Specific gravity is not often specified for natural cements.

The presence of the volatile elements due to incomplete burning, or of adulterations added after the burning, tends to lower the specific gravity. The quantity of adulteration, however, needs to be considerable before it becomes appreciable in the results of this test. Chemical composition also to some extent affects the specific gravity, cements of low hydraulic index giving the highest values. The age of the cement is also important, as aeration tends to reduce the specific gravity below that of fresh cement. The specific gravity, unlike the apparent density, is not affected by the fineness of the cement.

This test is not commonly applied in specifications for the reception of cement upon ordinary engineering work.

Art. 39. Tests for Fineness.

The fineness to which a cement is ground is usually considered a matter of importance, as upon it depends very greatly the early adhesive strength of the mortar and the ability of the cement to take sand.

A test for fineness is nearly always included in specifications for cement, and the test is particularly necessary where the tensile strength is tested for neat cement only. In such case the attainment of a proper strength neat, together with a fair degree of fineness, practically insures

that the cement will give good results when used with sand.

The fineness which should be required is largely a matter of relative economy; the finer the cement, the larger the quantity of sand that may legitimately be used with it. The coarse parts of the cement are to be considered as inert material, or practically as a certain amount of sand already mixed with the cement. It is a question therefore of relative costs of different degrees of fineness.

There is, however, some dispute as to the value of fineness. Some European authorities question the wisdom of a fineness test. It is well known that the effect of fineness in the strength of sand mortar disappears to some extent with time, but the impalpable powder seems to be the really valuable part of the cement, and if this be omitted the cement loses its value.

Prof. Le Chatelier in his microscopic examination of mortar found that, after setting, in the more fine particles no trace is left of the grains of the cement. With the larger ones the central part of the grain remains unaltered. It seems that the grains which are completely attacked are limited to 0.1 millimeter in diameter, but further study is needed upon this point.

Coarse grinding also, as has been elsewhere noted, increases the intensity of the action of expansives which may be contained in the cement, causing a coarse-ground cement to expand and crack, when perhaps if finely ground it would be unaffected.

The test for fineness simply consists in sifting the cement through a sieve or a set of sieves and observing the amount retained by each sieve.

The Committee of the American Society of Civil Engineers in 1904 recommended with reference to the fineness test as follows:

"*Significance.*—It is generally accepted that the coarser particles in cement are practically inert, and it is only the extremely fine powder that possesses adhesive or cementing qualities. The more finely cement is pulverized, all other conditions being the same, the more sand it will carry and produce a mortar of a given strength.

"The degree of final pulverization which the cement receives at the place of manufacture is ascertained by measuring the residue retained on certain sieves. Those known as the No. 100 and No. 200 sieves are recommended for this purpose.

"*Apparatus.*—The sieves should be circular, about 20 cm. (7.87 inches) in diameter, 6 cm. (2.36 inches) high, and provided with a pan, 5 cm. (1.97 inches) deep, and a cover.

"The wire cloth should be woven (not twilled) from brass wire having the following diameters:

No. 100, 0.0045 inch; No. 200, 0.0024 inch.

"This cloth should be mounted on the frames without distortion; the mesh should be regular in spacing, and be within the following limits:

No. 100, 96 to 100 meshes to the linear inch.
No. 200, 188 to 200 " " " " "

"Fifty grams (1.76 oz.) or 100 gr. (3.52 oz.) should be used for the test, and dried at a temperature of 100° C. (212° F.) prior to sieving.

"*Method.*—The Committee, after careful investigation, has reached the conclusion that mechanical sieving is not as practicable or efficient as hand-work, and, therefore, recommends the following method:

"The thoroughly dried and coarsely screened sample is weighed and placed on the No. 200 sieve, which, with pan and cover attached, is held in one hand in a slightly inclined position, and moved forward and backward, at the same time striking the side gently with the palm of the other hand, at the rate of about 200 strokes per minute. The operation is continued until not more than one tenth of 1 per cent passes through after one minute of continuous sieving. The residue is weighed, then placed on the No. 100 sieve and the operation repeated. The work may be expedited by placing in the sieve a small quantity of large shot. The results should be reported to the nearest tenth of 1 per cent."

The British Standard Specifications, adopted by the Engineering Standards Committee in 1904, contain the following requirements for fineness:

6. The cement shall be ground to comply with the following degrees of fineness, viz.:

The residue on a sieve $76 \times 76 = 5776$ meshes per square inch is not to exceed 5 per cent.

The residue on a sieve $180 \times 180 = 32,400$ meshes per square inch is not to exceed $22\frac{1}{2}$ per cent.

The sieves are to be prepared from standard wire, the size of the wire for the 5776 mesh is to be .0044 inch, and for the 32,400 mesh, .0018 inch. The wire shall be woven (not twilled), the cloth being carefully mounted on the frames without distortion.

Art. 40. Normal Consistency.

In order to secure uniform results in tests for strength as well as for rate of setting, it is essential that a standard consistency be adopted for the cement paste, or mortar. The effects upon setting and hardening of varying the quantity of water used in mixing have already been discussed in Art. 24.

In making standard tests it is common to regulate the quantity of water by trying to bring the paste to a normal consistency which shall be uniform for all tests. Different cements require very different quantities of water to reach the same consistency, and in the use of sand mortar the nature and condition of the sand may also cause considerable variation. It should also be noted that the consistency of paste does not depend altogether upon the quantity of water used, but may be varied by the manner and extent of working the paste during the gauging. In French and German practice it is required that the paste be vigorously worked for five minutes.

Under the different systems of making briquettes there are two consistencies employed as standards—the plastic and the dry. In using each of these methods the quantity of water used and the consistency reached vary greatly in different places, as the man doing the work may interpret the terms used in describing the desired state of the paste.

The method of determining normal consistency adopted by the Committee of the American Society of Civil Engineers in 1904 is as follows:

NORMAL CONSISTENCY.

"*Significance.*—The use of a proper percentage of water in making the pastes * from which pats, tests of setting, and briquettes are made is exceedingly important and affects vitally the results obtained.

"The determination consists in measuring the amount of water required to reduce the cement to a given state of plasticity, or to what is usually designated the normal consistency.

"Various methods have been proposed for making this determination, none of which has been found entirely satisfactory. The committee recommends the following:

"*Method. Vicat Needle Apparatus.* —This consists (Fig. 8) of a frame bearing a movable rod, with the cap at one end and at the other end the cylinder, 1 cm. (0.39 inch) in diameter, the cap, rod, and cylinder weighing 300 gr. (10.58 oz.). The rod, which can be held in any desired position by a screw, carries an indicator, which moves over a scale (graduated to centimeters) attached to the frame. The paste is held by a conical, hard-rubber ring, 7 cm. (2.76 inches) in diameter at the base, 4 cm. (1.57 inches) high, resting on a glass plate about 10 cm. (3.94 inches) square.

"In making the determination, the same quantity of cement as will be subsequently used for each batch in making the briquettes (but not less than 500 gr.) is kneaded into a paste as described in paragraph 58, and quickly formed into a ball with the hands, completing

* The term "paste" is used in this report to designate a mixture of cement and water, and the word "mortar" a mixture of cement, sand, and water.

the operation by tossing it six times from one hand to the other, maintained 6 inches apart; the ball is then pressed into the rubber ring through the larger opening, smoothed off, and placed on a glass plate (on its large end) and the smaller end smoothed off with a trowel; the paste confined in the ring resting on the plate is placed under the rod bearing the cylinder, which is brought in contact with the surface and quickly released.

"The paste is of normal consistency when the cylinder penetrates to a point in the mass 10 mm. (0.39 inch) below the top of the ring. Great care must be taken to fill the ring exactly to the top.

"The trial pastes are made with varying percentages of water until the correct consistency is obtained.

"The Committee has recommended as normal a paste the consistency of which is rather wet, because it believes that variations in the amount of compression to which the briquette is subjected in moulding are likely to be less with such a paste.

"Having determined in this manner the proper percentage of water required to produce a neat paste of normal consistency, the proper percentage required for the sand mortars is obtained from an empirical formula.

"The committee hopes to devise such a formula. The subject proves to be a very difficult one, and, although the Committee has given it much study, it is not yet prepared to make a definite recommendation."

This general method was originally proposed by Professor Tetmajer and was adopted by the European Commission upon Testing Materials in 1892, and approved by the French Commission in 1895. In Europe a somewhat more safe consistency is employed than in the Ameri-

can recommendations, the requirement being that the plunger shall sink to a point 6 millimeters from the bottom of the paste for standard consistency.

Another method somewhat used in France and approved by the French Commission in 1895 is known as the Boulogne method. The method is as follows:

The paste is to be vigorously worked for five minutes to bring it to the required consistency.

"1. The consistency of the paste should not change sensibly if the mixing be continued three minutes after the expiration of the required five minutes.

"2. If a small quantity of the paste be taken upon the trowel and allowed to fall upon the mixing-slab from a height of 50 centimeters it should be detached from the trowel without leaving any small particles adhering, and after falling should approximately retain its form without cracking.

"3. A small quantity taken in the hand and patted into a round form until water flushes to the surface should not stick to the hand, and when allowed to fall from a height of one half meter the ball should retain its rounded form without showing any cracks."

To meet these requirements leaves but a narrow limit within which the consistency may vary. If a slightly too small quantity of water be used, the paste would crack upon falling. If the quantity be very slightly too great, the paste continues to soften upon further working, becomes sticky, and loses its form upon falling.

These methods of determining consistency are not applicable to mortar made with sand, and no satisfactory method has yet been devised for securing uniform consistency for sand mortars.

The Committee of the American Society for Testing Materials in 1904 suggest the percentages given in the following table, the percentage for neat cement to be first determined by the test above given for normal consistency.

PERCENTAGE OF WATER FOR CEMENT MORTARS OF NORMAL CONSISTENCY.

Percentage Water for Neat Cement.	Proportions Cement to Sand by Weight.					Percentage Water for Neat Cement.	Proportions Cement to Sand by Weight.				
	1-1	1-2	1-3	1-4	1-5		1-1	1-2	1-3	1-4	1-5
18	12.0	10.0	9.0	8.4	8.0	30	16.0	12.7	11.0	10.0	9.3
19	12.3	10.2	9.2	8.5	8.1	31	16.3	12.9	11.2	10.1	9.4
20	12.7	10.4	9.3	8.7	8.2	32	16.7	13.1	11.3	10.3	9.5
21	13.0	10.7	9.5	8.8	8.3	33	17.0	13.3	11.5	10.4	9.6
22	13.3	10.9	9.7	8.9	8.4	34	17.3	13.6	11.7	10.5	9.7
23	13.7	11.1	9.8	9.1	8.5	35	17.7	13.8	11.8	10.7	9.9
24	14.0	11.3	10.0	9.2	8.6	36	18.0	14.0	12.0	10.8	10.0
25	14.3	11.6	10.2	9.3	8.8	37	18.3	14.2	12.2	10.9	10.1
26	14.7	11.8	10.3	9.5	8.9	38	18.7	14.4	12.3	11.1	10.2
27	15.0	12.0	10.5	9.6	9.0	39	19.0	14.7	12.5	11.2	10.3
28	15.3	12.2	10.7	9.7	9.1	40	19.3	14.9	12.7	11.3	10.4
29	15.7	12.5	10.8	9.9	9.2						

Art 41. Rate of Setting.

The rate of setting of cement is tested for the purpose of determining if it be suitable for a given use, and not as a measure of the quality of the material. For most purposes, where immediate setting is not required to prevent disturbance of the mortar before hardening, the moderately slow-setting cements are found most convenient, as they need not be handled so quickly and may be mixed in somewhat larger quantities.

Testing for time of setting consists in arbitrarily fixing two points in the process of consolidation, which are called the beginning and the end of setting. These points are differently determined in the various methods of testing, and are not marked by any distinguishing phenomena which admit of definite determination.

A method of testing for rate of setting proposed by General Gilmore and recommended by the Committee of the American Society of Civil Engineers in 1885 is still quite largely used in the United States. It consists in mixing cakes of neat cement, about 2 or 3 inches in diameter and 1/2 inch thick, to a stiff plastic consistency, observing the time when they will bear a needle 1/12 inch in diameter sustaining a weight of 1/4 pound, and noting this as the beginning of setting; then continuing the observations with a needle 1/24 inch in diameter carrying a weight of one pound until the material is sufficiently firm to bear this, when it may be called fully set.

The time of setting is often roughly determined in practice by making small cakes of mortar and observing when they will resist penetration under a light pressure of the thumb-nail. This is a standard test in Germany.

For ordinary practical purposes these methods are sufficiently accurate, as all that is necessary is to know whether the cement sets quickly or slowly, but for experimental and comparative purposes more elaborate methods are valuable. The beginning of setting is the point of most value, as the cement in practice should be used before that point is reached, in order that it may not be disturbed after the stiffening has begun.

In Germany and France the Vicat needle is commonly employed for accurate determinations. This ar-

rangement is shown in Fig. 8. By this method a briquette of neat cement is made in a cylindrical brass or rubber mould 10 centimeters in diameter and 4 centimeters high, placed upon a plate of glass or metal, the cement being mixed to a plastic consistency as determined by the consistency test. The apparatus is so arranged that a weight of 300 grammes may be brought either

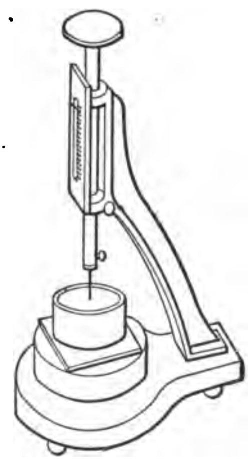

FIG. 8.

upon a needle of 1 square millimeter section, or upon a cylindrical plunger 1 centimeter in diameter, and allowed to settle into the cement, the depth of penetration being shown by a scale along which the weight slides. As soon as the mould is filled with the mortar it is placed in the apparatus, and the plunger sustaining the 300 grammes is brought to the surface of the briquette and allowed to sink into it. If the plunger penetrates to a point 6 millimeters from the bottom the mortar is of proper consistency for the test. The needle is then substituted for the plunger,

and the time when the needle first refuses to sink entirely through the mortar is observed and noted as the beginning of setting; the time when the needle first rests upon the briquette without penetrating it is considered the end of setting.

The accurate determination by this method of the points where the set is said to begin and end is a matter of some difficulty, as the lack of perfect homogeneity causes the needle to sink more deeply in some parts than in others, and the cement sets more rapidly at the circumference than in the interior of the mass. However, these defects are not very serious when due care is exercised in mixing the mortar, and the penetration is not taken too near the edges. The time of completion of set is much less well defined than that of beginning of set, as there is usually a considerable period during which a very slight penetration takes place, decreasing insensibly to final disappearance. The point to be used for completion of the set is that at which the penetration becomes very small, so that the curve of penetrations becomes practically horizontal. Such a point is usually fairly well defined.

The Committee of the American Society of Civil Engineers in 1904 recommend the use of the Vicat needle slightly modified from the foregoing with mortar of somewhat stiffer consistency. The method recommended is as follows:

"*Significance.*—The object of this test is to determine the time which elapses from the moment water is added until the paste ceases to be fluid and plastic (called the 'initial set'), and also the time required for it to acquire a certain degree of hardness (called the 'final' or 'hard

set'). The former of these is the more important, since, with the commencement of setting, the process of crystallization or hardening is said to begin. As a disturbance of this process may produce a loss of strength, it is desirable to complete the operation of mixing and moulding or incorporating the mortar into the work before the cement begins to set.

"It is usual to measure arbitrarily the beginning and end of the setting by the penetration of weighted wires of given diameters.

"*Method.*—For this purpose the Vicat needle, which has already been described in paragraph 30, should be used.

"In making the test, a paste of normal consistency is monlded and placed under the rod, as described in paragraph 31; this rod, bearing the cap at one end and the needle, 1 mm. (0.039 inch) in diameter, at the other, weighing 300 gr. (10.58 oz.). The needle is then carefully brought in contact with the surface of the paste and quickly released.

"The setting is said to have commenced when the needle ceases to pass a point 5 mm. (0.20 inch) above the upper surface of the glass plate, and is said to have terminated the moment the needle does not sink visibly into the mass.

"The test pieces should be stored in moist air during the test; this is accomplished by placing them on a rack over water contained in a pan and covered with a damp cloth, the cloth to be kept away from them by means of a wire screen; or they may be stored in a moist box or closet.

"Care should be taken to keep the needle clean, as

the collection of cement on the sides of the needle retards the penetration, while cement on the point reduces the area and tends to increase the penetration.

"The determination of the time of setting is only approximate, being materially affected by the temperatures of the mixing water, the temperature and humidity of the air during the test, the percentage of water used, and the amount of moulding the paste receives."

The time of setting is usually tested upon paste of neat cement, on account of the difficulty of obtaining a satisfactory test with sand mortar. The Vicat needle is quite useless when sand is employed because of the interference of the grains of sand with the descent of the needle. Rough tests of sand mortar by the ordinary methods may readily be made with sufficient accuracy for practical purposes, and are very desirable as showing more nearly what may be expected of the mortar when used. The rate of setting of neat mortar gives but little indication of what the action may be with sand. For different cements a mortar of 3 parts sand to 1 of cement may require from about 1½ to 8 or 10 times as long as neat paste when the same sand and method of mixing are employed.

Several propositions have been made with reference to a standard test for the purpose of comparing the rate of setting of sand mortars. These usually have been to substitute cylinders of larger diameter for the Vicat needle, in order to reduce the effect of the sand grains, and then to use correspondingly heavy weights to produce penetration. The usual method is to determine the weight necessary to indent the surface of the mortar. Thus in one apparatus a cylinder 1 cm. in diameter is

employed: when the mortar will just bear a weight of 400 grammes it is considered as beginning to set; when it will sustain 10,000 grammes the setting is complete.

M. Feret has also proposed to make standard tests by using fine sand composed of grains which pass the sieve of 75 meshes and are held by one of 180 meshes per linear inch, the test being made as for neat cement with the Vicat needle. This serves as a comparison of the effects of sand upon different cements.

In making tests for rate of setting, the temperature of the ingredients of the mortar before gauging, that of the atmosphere in which it is gauged, and of the air or water in which it is placed during setting have a very large influence upon the results. A temperature of 60° to 65° Fahr. is usually accepted as standard, although the air in the laboratory may have a somewhat higher temperature—perhaps 65° to 70°.

Change of Temperature During Setting.

Observations of the change of temperature during setting are commonly taken in many of the European laboratories. It has been thought by some observers that the points of beginning and end of setting might be more accurately marked by observing the change of temperature than by the needle test. The operation of setting is a chemical action which takes place with the disengagement of heat, but in many cases the rise in temperature is so slight and indefinitely marked that it would be difficult to use it in this manner. The amount of the variation in temperature varies somewhat with the activity of the cement, increasing rapidly as the cement

sets more quickly. The total rise of a quick-setting cement may reach 15° or 20°, while in a very slow one it may be quite imperceptible.

The change in temperature also varies with the nature of the cement, and attempts have been made to connect it with the soundness of the material, particularly the presence of free lime. This, however, does not seem to be supported by facts, or at least the indications are very indefinite. Expansives which are slow in action, and therefore dangerous in the cement, are not likely to cause increase in temperature during setting.

The test for change in temperature is ordinarily made by placing the mortar in a cylindrical mould, like that used with the Vicat needle, fitted with a cover through which is an opening to permit the introduction of the thermometer. This cover prevents the mortar coming into contact with the air or water in which it may be placed, thus neutralizing the effect of the internal change of temperature.

Some very slow-setting cements show a fall in temperature if left exposed to the air while setting, probably due to surface evaporation.

This test does not seem of importance as a measure of the quality of cement, but it is worthy of attention in a systematic study of the properties of the material, and may be capable of giving interesting results.

CHAPTER VI.

TESTS OF THE STRENGTH OF MORTAR.

ART. 42. METHODS EMPLOYED.

THE strength of mortar is frequently tested in three ways: the tensile test is the one more commonly employed, but compressive and transverse tests are also often used.

The test for tensile strength is made by making briquettes of the mortar in moulds having a definite section at the middle,—in the United States usually one inch square,—and enlarging at the ends to fit in clips by which they may be placed in the testing-machine and pulled apart by direct tension. This test is in common use, because it can be more readily and uniformly applied than the others, and seems, when coupled with other tests, to give a satisfactory indication of the value of the material.

The compressive test consists in crushing small blocks of the mortar between the jaws of the testing-machine and weighing the force required. This test is more difficult in manipulation to secure uniform results, and also requires much heavier appliances, on account of the high resistance offered by the material to crushing.

The transverse test is made by moulding the mortar into bars, the bar is a afterwards placed horizontally upon supports near its ends, and broken by a load brought upon its middle, causing it to break by bending.

The proper conduct of any test for strength is a matter requiring care and experience. There are many points connected with the circumstances and manipulation of the work which have an important bearing upon the result. These are: the form of the briquette; the method of mixing and moulding; the amount of water used in tempering the mortar; the surroundings in which the mortar is kept during the hardening; the rate and manner of applying the stress; the temperature at which all of the operations are performed. In order to secure uniform results it is essential that the tests be standardized in all of these particulars. Much has been accomplished in this direction during recent years, but there is still great disparity in the results of different operators, undoubtedly due mainly to differences in making the briquettes.

Every laborator seems to have to a certain extent its own practice, which makes its work incomparable with that of any other laboratory. Even where presumably the same methods are used it is very difficult to frame rules that all will understand alike, while in all cases the personal equation of the operator is an important matter in hand-work.

The committee upon standard tests of the American Society of Civil Engineers in their report in 1885 call attention to this matter in the following words:

"The testing of cement is not so simple a process as it is sometimes thought to be. No small degree of experience is necessary before one can manipulate the

materials so as to obtain even approximately accurate results.

"The first tests of inexperienced though intelligent and careful persons are usually very contradictory and inaccurate, and no amount of experience can eliminate the variations introduced by the personal equation of the most conscientious observers. Many things, apparently of minor importance, exert such a marked influence upon the results that it is only by the greatest care in every particular, aided by experience and intelligence, that trustworthy tests can be made."

Experience since the report of the committee was made has shown that the difficulties in the way of uniformity in such tests are much greater than was then imagined.

The variations in the results of the tensile test between the work of different experienced operators working by the same method and upon the same material are frequently very large, and often make all the difference between the acceptance and rejection of the cement. Differences of 40% to 60% with neat cement are not uncommon, while for sand mortar they are much greater.

An investigation of this matter by Prof. J. M. Porter, of Lafayette College, is interesting in this connection. He divided a sample of cement into a number of parts, sending each to a different laboratory with the request that tests be made of it in 1 to 3 mortar, according to the rules recommended by the committee of the American Society of Civil Engineers. The resulting average strengths of each of the nine laboratories were as follows, in pounds per square inch: 75, 102, 114, 133 and 140, 153, 163, 176, 225, 247. These results (see *Engineering*

News, March 5, 1896) show that the lowest strength was but 30% of the highest, while the remainder were quite evenly distributed between the two extremes. Each result was the average of five briquettes, which agree fairly well among themselves.

If the results of experienced men in the permanent laboratories vary so much, what is to be expected of tests made by less experienced men for the reception of material upon temporary work, and how can a specification be framed which shall fairly determine the value of the material? Evidently, to secure proper results with hand-work, the inspector must first be calibrated, and the specifications drawn in accordance with the practice of the laboratory. It is at least very desirable that some means be devised by which the work of these tests may be made automatically, and the personal factor eliminated in so far as possible.

In standard tests it is customary to adopt a nearly constant temperature of 60° to 65° Fahr. for the air in the laboratory in which the briquettes are prepared and the tests made, and about the same or slightly less for the water used in tempering and that in which the mortar is immersed during hardening.

Art. 43. Form of Briquette.

Briquettes of mortar for tests of strength are commonly formed in moulds of metal of the form to be used in the tests. As the size and shape of the specimens have an important effect upon the result, it is necessary to adopt standard dimensions in order to obtain uniform results.

For compressive tests a parallelopiped, usually a cube,

is employed. In the United States a cube whose edges are each two inches in length is commonly used, although sometimes an inch cube is used. In Europe generally the standard specimen is a cube with edges seven centimeters in length.

The French "Commission upon Methods of Testing Materials," however, rejected the rectangular section for compression specimens on the ground that it is difficult to so fill the corners of the moulds as to make homogeneous briquettes, and they recommend the cylindrical form as preferable. They also recommend the use of half-briquettes obtained by the tension test as blocks for the crushing test.

For transverse tests bars of rectangular section are used. Different experimenters have used quite different dimensions, and there is no size which may reasonably be called a standard. Those who have proposed the adoption of this test in place of that for tension in the acceptance of material have usually advocated a test-piece of a section one inch square and from eight to twelve inches long, although sometimes the section is made two inches square.

For tensile tests many forms of briquettes have been tried, but at present there are but two in common use: the one recommended by the committee of the American Society of Civil Engineers (shown in Fig. 9), which was derived from that used by Mr. Grant in England, is now the standard in the United States, and commonly used in England; the other is the form adopted by the Association of German Cement Makers, and is the standard in Germany, and generally employed in France. This form is shown in Fig. 10, which gives the dimensions in milli-

meters. The middle section is 22.5 mm. wide by 22.2 mm. thick, giving a cross-section of 5 square centimeters.

Comparative tests of briquettes of the two forms indicate that the English form gives higher results than the German, the difference being commonly for neat briquettes as much as 30% to 40% of the smaller. This may perhaps be accounted for by the fact, stated by Mr. Faija, that a sudden change of cross-section is always an element of weakness, and while the English form diminishes gradually from the ends to the middle, in the German

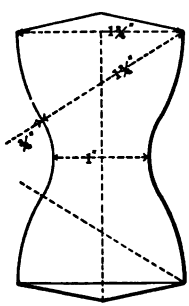

FIG. 9.

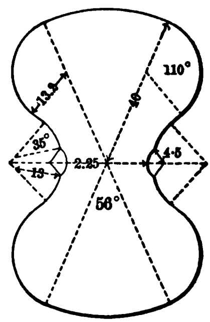

FIG. 10.

form the area is suddenly decreased by a circular notch at the middle.

It may also be noted that the surface upon which the clip catches the briquette when being tested is in the German form inclined at a greater angle to the centre line of the briquette, and consequently the adjustment in the clips to produce axial stress is less perfect.

In England and the United States the standard area for the middle is one square inch; in Germany and France a little smaller, being, as already noted, five square centi-

meters. The use of these small sections is advantageous, as it admits of lighter apparatus in making the test, and because greater uniformity is easily attainable in making the briquette. The work also is facilitated by the fact that less mortar is required for each specimen than with larger sections, so that more briquettes may be prepared from each mixing.

The size of the breaking section has an important effect upon the strength, the smaller sections giving much higher strength per unit of area than the larger ones. Thus for neat cement a change from a section 1 inch square to one 2 inches square has been found to lessen the tensile strength per square inch to about one half that of the smaller section. M. Durand-Claye has shown that the strength varies more nearly with the perimeter of the section than with its area, and that the interior may be removed without loss of strength.

M. Alexandre made a number of experiments upon the relative strengths of briquettes of different sizes.* He found that large briquettes gave much less strength per unit area than small ones, but for sand mortars the effect diminished as the proportion of sand increased, and the difference also became less as the age of the mortar increased, seeming to indicate that the effect may be partly due to the more perfect hardening of the small specimens.

The Committee of the American Society of Civil Engineers in 1904 recommended the continued use of the old form (Fig. 9) with slight modifications. They say:

---

* Annales des Ponts et Chaussées, 1890, vol. II. p. 277.

"While the form of the briquette recommended by a former Committee of the Society is not wholly satisfactory, this Committee is not prepared to suggest any change other than rounding off of the corners by curves of ½ inch radius.

"The moulds should be made of brass, bronze, or some equally non-corrodible material having sufficient metal in the sides to prevent spreading during moulding.

"Gang moulds, which permit moulding a number of briquettes at one time, are preferred by many to single moulds, since the greater quantity of mortar that can be mixed tends to produce greater uniformity in the results.

"The moulds should be wiped with an oily cloth before using."

ART. 44. STANDARD SAND.

Tests with sand may be made either as a means of judging the value of the cement or to determine the probable strength of mortar under the circumstances which may obtain in special work. When the tests are intended as a determination of value it is essential that they be made according to some standard forming ready means of comparison with other material. This requires that the specimens be made and tested according to standard methods, and that the sand used be of standard quality.

In the German specifications the standard sand is described as follows: "In order to obtain concordant results in the tests, sand of uniform size of grain and uniform quality must be used. This standard sand is

obtained by washing and drying the purest quartz sand obtainable, sifting the same through a sieve of 60 meshes per square centimeter, thereby separating the coarsest particles, and by removing from the sand so obtained, by means of a sieve of 120 meshes per square centimeter, the finest particles. The diameters for the wires of the sieve shall be 0.38 millimeter and 0.32 millimeter respectively." The German Conference upon Uniform Tests specified Freienwalde sand as the standard.

In France both artificial sand (crushed quartz) and natural sand are used to some extent in tests. The Commission on Methods of Testing recommend the use of natural sand. They divide the sand into three sizes:

1. Sand which passes openings of 1 mm. and is retained by those of 0.5 mm. 2. Sand which passes openings of 1.5 mm. and is retained by those of 1.0 mm. 3. Sand which passes openings of 2.0 mm. and is retained by those of 1.5 mm.

The name *simple standard sand* is given to No. 2, and the name *compound standard sand* to a mixture of equal parts of the three sizes. The former is to be used in making mortar for standard tests where the dry consistency is employed and the briquettes made by pounding. The latter is required in gauging when the plastic consistency is used.

The Committee of the American Society of Civil Engineers reporting in 1885 recommended the use of crushed quartz as a standard sand. This is largely in use in the United States, but the Committee reporting in 1904 recommend the use of natural sand as follows:

STANDARD SAND.

"The Committee recognizes the grave objections to the standard quartz now generally used, especially on account of its high percentage of voids, the difficulty of compacting in the moulds, and its lack of uniformity; it has spent much time in investigating the various natural sands which appeared to be available and suitable for use.

"For the present, the Committee recommends the natural sand from Ottawa, Ill., screened to pass a sieve having 20 meshes per linear inch and retained on a sieve having 30 meshes per linear inch, the wires to have diameters of 0.0165 and 0.0112 inch, respectively; i.e., half the width of the opening in each case. Sand having passed the No. 20 sieve shall be considered standard when not more than 1 per cent passes a No. 30 sieve after one minute continuous sifting of a 500-gr. sample.

"The Sandusky Portland Cement Company, of Sandusky, Ohio, has agreed to undertake the preparation of this sand, and to furnish it at a price only sufficient to cover the actual cost of preparation."

The use of standard sand is a matter of considerable importance, as natural sands may have very different values for use in mortar while quite similar in appearance and screened in the same manner.

Tests of sand mortar for the purpose of comparing various sands with the standard sand, or of estimating the efficiency of mortar under varying circumstances of use, are often of much value as a guide to the proper use of the material. In such work the method of testing necessarily depends upon the point to be investigated.

Complete tests should include an examination of the

nature of the sand; its fineness as shown by the amount retained by various sieves; the form of grain, which may be examined under a glass; its specific gravity or the weight of a unit volume; its mineralogical character. Tests of the tensile strength of mortar made from the sand to be tested as compared with similar tests made upon standard sand are of most importance as indicating the value of the sand to combine with cement in forming mortar.

ART. 45. METHODS OF MAKING BRIQUETTES.

The wide differences commonly found in the results of tensile tests made by different men are, without doubt, mainly due to differences in making the briquettes. Probably if the other strength tests were as commonly used as that of tension the same want of uniformity would be observable in them. These differences occur, not only in the work of novices, but in that of skilled operators, who, while able to maintain practical unformity in their own work, disagree in results with each other when experimenting upon the same material and apparently using the same methods. The extent of this difficulty has already been alluded to in Art. 42.

In order to secure uniform results it is essential that a uniform procedure be adopted as to all the operations of forming the briquette. The points of importance are the quantity of water used in tempering, the method of gauging, and amount of working to which the mortar is subjected in bringing it to a proper consistency, and

the method of forming the briquette and amount of force used in placing the mortar in the mould.

In making briquettes by hand two general methods are employed corresponding to different consistencies of the mortar. The plastic method is most commonly employed, being used in England, France, and the United States, while the dry method is standard in Germany.

The report of the French commission upon standard tests in 1892 recommends the following method:

"The moulds are placed upon a plate of marble or polished metal which has been well cleaned and rubbed with an oiled cloth. Six moulds are filled from each gauging if the cement be slow-setting and four if it be quick-setting. Sufficient material is at once placed in each mould to more than fill it. The mortar is pressed into the mould with the fingers so as to leave no voids and the side of the mould tapped several times with the trowel to assist in disengaging the bubbles of air. The excess of mortar is then removed by sliding a knife-blade over the top of the mould so as to produce no compression upon the mortar.

"The briquettes are removed from the moulds when sufficiently firm, and are allowed to remain for 24 hours upon the plate in a moist atmosphere, protected from currents of air or the direct rays of the sun, and at a nearly constant temperature of 15° to 18° C. They are then placed in the surroundings in which they are to be kept until the time for breaking. With quick-setting cements the delay is reduced from 24 hours to 1 hour for neat cement and 3 hours for sand mortar.

"It is recommended to weigh the briquettes after

removing them from the moulds to make sure of the regularity of their formation."

A method somewhat in use in France for sand mortar is that proposed by M. Candlot, and recommended by the Commission upon Methods of Testing Materials, for use with sand mortars. It is as follows:

"Sufficient mortar is gauged at once to make six briquettes, requiring 250 grammes of cement and 750 grammes of normal sand. The weight of water necessary exceeds by 30 grammes the amount necessary to bring the cement alone to *normal consistency*."

The mortar is prepared in the ordinary manner. In forming the briquette the mould is placed upon a metal plate and a guide fitted above it having the same section as the mould and a height of 125 millimeters.

"180 grammes of mortar are introduced and roughly distributed in the mould and guide with a rod. By means of a metallic pestle weighing 1 kilogramme, and with a base of the form of the briquette but of slightly less dimensions, the mortar is pounded softly at first, then stronger and stronger until a little water escapes under the bottom of the mould.

"The pestle and guide are then removed and the mortar cut off level with the top of the mould."

It is claimed that by this method very uniform results have been obtained.

By the dry method the mortar is mixed with less water than in the above, and the mould is filled and heaped with it. It is then rammed into place and pounded until the water flushes to the surface, after which the briquette is struck off level, and when hard enough is taken from the mould and treated as in the other case.

Following are the specifications adopted by the Association of German Cement Makers: *

"On a metal or thick-glass plate five sheets of blotting-paper soaked in water are laid, and on these are placed five moulds wetted with water. 250 grammes of cement and 750 grammes of standard sand are weighed and thoroughly mixed dry in a vessel; then 100 cubic centimeters of fresh water are added, and the whole mass mixed for five minutes. With the mortar so obtained the moulds are at once filled, with one filling, so high as to be rounded on top, the mortar being well pressed in. By means of an iron trowel, 5 to 8 centimeters wide, 35 centimeters long, and weighing about 250 grammes, the projecting mortar is pounded, first gently and from the sides, then harder into the moulds, until the mortar grows elastic and water flushes to the surface. A pounding of at least one minute is necessary. An additional filling and pounding in of the mortar is not admissible, since the test-pieces of the same cement should have the same density at the different testing stations. The mass is now cut off with a knife and the surface smoothed. The mould is carefully taken off and the test-piece placed in a box lined with zinc, which is to be provided with a cover to prevent a non-uniform drying of the test-pieces at different temperatures."

For making the test-pieces of *neat cement:* "The inside of the moulds are slightly oiled, and the same are placed on a metal or glass plate without blotting-paper; 1000 grammes of cement are weighed out, 200 grammes of water added, and the whole mass thoroughly mixed

---

* *Engineering News*, Nov. 13, 1886.

for five minutes. The forms are well filled, and then proceed as for hand-work with sand mortar.

"The mould can only be taken off after the cement has sufficiently hardened.

"The quantity of water for finely ground or quick-setting cements must be increased."

The rules recommended by the committee of the American Society of Civil Engineers in 1904 give the following method of making briquettes.

MIXING.

"All proportions should be stated by weight; the quantity of water to be used should be stated as a percentage of the dry material.

"The metric system is recommended because of the convenient relation of the gramme and the cubic centimeter.

"The temperature of the room and the mixing water should be as near 21° C. (70° F.) as it is practicable to maintain it.

"The sand and cement should be thoroughly mixed dry. The mixing should be done on some non-absorbing surface, preferably plate glass. If the mixing must be done on an absorbing surface, it should be thoroughly dampened prior to use.

"The quantity of material to be mixed at one time depends on the number of test pieces to be made; about 1000 gr. (35.28 oz.) makes a convenient quantity to mix, especially by hand methods.

"*Method.*—The material is weighed and placed on the mixing table, and a crater formed in the center, into which the proper percentage of clean water is poured; the material on the outer edge is turned into the crater

by the aid of a trowel. As soon as the water has been absorbed, which should not require more than one minute, the operation is completed by vigorously kneading with the hands for an additional $1\frac{1}{2}$ minutes, the process being similar to that used in kneading dough. A sand-glass affords a convenient guide for the time of kneading. During the operation of mixing the hands should be protected by gloves, preferably of rubber.

MOULDING.

"Having worked the paste or mortar to the proper consistency, it is at once placed in the moulds by hand.

"The Committee has been unable to secure satisfactory results with the present moulding-machines; the operation of machine moulding is very slow, and the present types permit of moulding but one briquette at a time, and are not practicable with the pastes or mortars herein recommended.

"*Method.*—The moulds should be filled at once, the material pressed in firmly with the fingers and smoothed off with a trowel without ramming; the material should be heaped up on the upper surface of the mould, and, in smoothing off, the trowel should be drawn over the mould in such a manner as to exert a moderate pressure on the excess material. The mould should be turned over and the operation repeated.

"A check upon the uniformity of the mixing and moulding is afforded by weighing the briquettes just prior to immersion, or upon removal from the moist closet. Briquettes which vary in weight more than 3 per cent from the average should not be tested.

There are two points to be specially noted in mak-

ing briquettes by hand: first, the mortar must be very thoroughly worked in gauging; both the German and French rules require that it shall be briskly mixed for at least five minutes, only sufficient mortar being prepared at once for five or six briquettes; second, the air-bubbles must be well worked out of the mortar in filling the moulds. The neglect of these precautions causes much of the irregularity which commonly exists in the work of inexperienced operators.

It is perhaps easier to secure uniform results with the dry than with the plastic method. The greater density of the hammered briquette also gives it higher strength. The plastic method, however, accords more nearly with the conditions of the use of the material in practice.

Even with the most experienced operators there exist differences in the amount of working, the pressure given in forming the briquette, and the quantity of water used, which cause wide variations in result.

In order to secure good results in tests of strength it is necessary that the briquettes should be kept in a moist condition during setting and the first period of hardening. For this purpose it is customary in the United States to cover the briquettes with wet cloths after moulding and until submerging them.

The Committee of the American Society of Civil Engineers recommended as follows:

STORAGE OF THE TEST PIECES.

"During the first twenty-four hours after moulding, the test pieces should be kept in moist air to prevent them from drying out.

"A moist closet or chamber is so easily devised that the use of the damp cloth should be abandoned if possible. Covering the test pieces with a damp cloth is objectionable, as commonly used, because the cloth may dry out unequally, and, in consequence, all the test pieces are not maintained under the same condition. Where a moist closet is not available, a cloth may be used and kept uniformly wet by immersing the ends in water. It should be kept from direct contact with the test pieces by means of a wire screen or some similar arrangement.

"A moist closet consists of a soapstone or slate box, or a metal-lined wooden box, the metal lining being covered with felt and this felt kept wet. The bottom of the box is so constructed as to hold water, and the sides are provided with cleats for holding glass shelves on which to place the briquettes. Care should be taken to keep the air in the closet uniformly moist.

"After twenty-four hours in moist air, the test piece for longer periods should be immersed in water maintained as near 21° C. (70° F.) as practicable; they may be stored in tanks or pans, which should be of non-corrodible material.

Art. 46. Mechanical Appliances for Making Briquettes.

In order to reduce the effect of the personality of the operator in making tests of the strength of cements, various appliances for gauging and moulding briquettes by machinery have been proposed and tried.

Greater uniformity in these tests is highly desirable, and it seems possible to reach it only by the application of automatic appliances in making the briquettes.

No entirely satisfactory system of automatic testing has as yet been devised. In Europe machines are quite commonly employed for moulding briquettes, but the mixing is done by hand in the ordinary manner.

In Germany and Switzerland all blocks for compressive tests are made by machine, as are many of the tensile specimens. The machine used for this purpose is either the Bohmé hammer or the Tetmajer apparatus.

The *Bohmé hammer*, designed by Dr. Bohmé of the Charlottenburg Experiment Station, is shown in Fig. 11. It consists of an arrangement by which the mortar

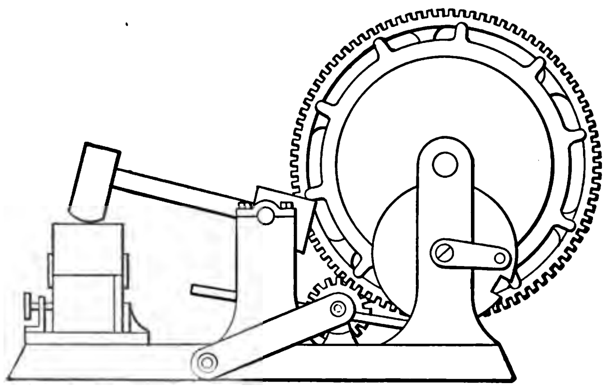

FIG. 11.

is compacted in the mould by a succession of blows struck by a hammer of the weight of two kilogrammes upon a plunger sliding in a guide-mould placed over the mould in which the briquette is to be formed.

The machine is arranged to lock after striking 150 blows. A high degree of density is thus produced in the briquette, and the air is thoroughly expelled. More regular results are thus obtained, depending much less

upon the personality of the operator than by the hand method. The arrangement of this apparatus, however, is such that its operation must be extremely slow, in order to give time for the hammer to strike a full blow without being caught on the next stroke, and the time required to make a briquette is too great to admit of its general use.

The rules of the Association of German Cement Makers specify this machine, and are as follows: * "In order to obtain concordant values in compression tests machine-making is necessary. 400 grammes of neat cement and 1200 grammes of dry standard sand are thoroughly mixed dry in a vessel, 160 cubic centimeters of water are added thereto, and then the mortar is thoroughly mixed for five minutes. Of this mortar 860 grammes are placed in the cubic mould, provided with guide-mould, and the mould is then screwed on the bed-plate under the pounding-machine. The iron follower is placed in the form, and by means of Bohmé's trip-hammer one hundred and fifty blows are struck by a hammer weighing 2 kilogrammes. After removing the guide-mould and follower the test-piece is smoothed off, taken with the mould from the bed-plate, and then treated as for hand-work."

The *Tetmajer apparatus* is similar in character to the Bohmé hammer. It consists of an iron rod carrying a weight upon its lower end, which is raised through a given height and dropped upon the mortar in the mould. The ram in this machine weighs 3 kilogrammes. This machine is used in the Zurich laboratory for both tensile and compressive specmiens, and Prof. Tetmajer regulates

* *Engineering News*, Nov. 13, 1886.

the number of blows by requiring a certain amount of work to be done upon a unit volume of mortar,—0.3 kilogrammeter of work per gramme of dry material of which the mortar is composed. This apparatus is subject to the same limitations in practice as the Bohmé hammer, in being very slow in use, and somewhat expensive in first cost of apparatus.

Canadian Method.—In Canada, and to some extent in England, the method has been adopted of gauging the mortar quite soft, using a high percentage of water with machine-mixing and then moulding the briquettes under light pressure—20 lbs. per square inch on the surface of the briquette. This gives much lower results for strength than the ordinary methods, which is unimportant provided the results are concordant, and specifications are made to agree with the method.

A number of tests made by Mr. Cecil B. Smith at the McGill University seem to show that the method is capable of yielding uniform results in so far as the variations of the individual tests from the mean of a single series is concerned. The method appears to be defective, however, in not affording a satisfactory method of determining the proper consistency of the mortar, upon which largely depends the comparability of the results of different observers.

The Jamieson briquette machine, shown in Fig. 12, was designed by Prof. Jamieson, of the Iowa State University, for the purpose of making briquettes under direct pressure, and is intended to secure rapid manipulation.

The following description is from *Engineering News* of February 7, 1891: "The principle of the machine

is very simple. A vertical cylinder (*a*) whose cross-section conforms to the outline of the standard briquette

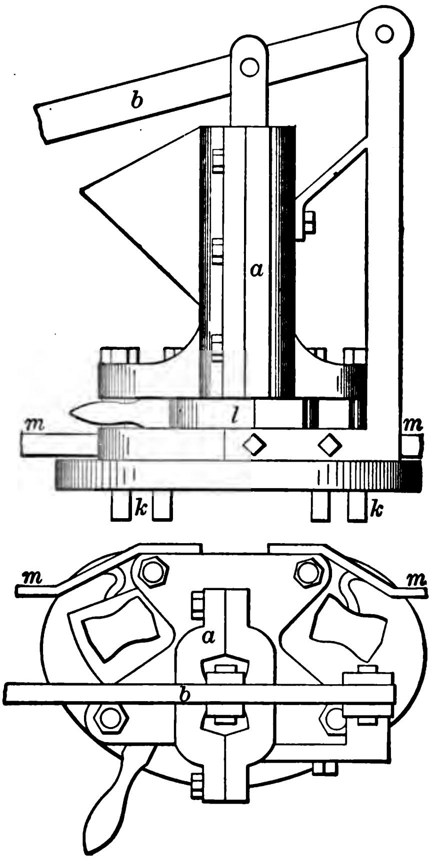

FIG. 12.

receives a charge of the mixed cement from a hopper at the side. In this cylinder a close-fitting piston is worked by a hand-lever (*b*), so that the charge of cement

in the cylinder may be subjected to a pressure of about 175 lbs. per square inch. The bottom of the cylinder is raised above the bed-plate a distance equal to the thickness of the briquette (1 inch), and in this space works a triangular block (*l*) having two holes of the same cross-section as the briquette. This block can be oscillated to bring either of these holes beneath the cylinder. When one hole is in this position, however, the other is clear of the cylinder at one side, and the briquette of cement which has been pressed into it can be lifted by a plunger, worked by a lever (*m*) and guided by the pins (*kk*). Owing to the pressure used the briquettes are hard enough to handle as soon as lifted from the mould, and they are at once removed and placed on a glass slab."

"In practical working it has been found possible to make briquettes as rapidly as 600 per hour."

This machine may be found useful in laboratories where large numbers of briquettes are needed for the purpose of comparing cements under various conditions, as it greatly lessens the manual labor of forming the briquette. It is to be observed, however, that the time occupied in making briquettes is largely used in mixing the mortar, and that rapid moulding involves equally rapid mixing. The machine, as designed, provides no means of regulating the amount of pressure applied in forming the briquette, which may vary with different operators, and is thus likely to produce variations in result. This may be comparatively unimportant for neat briquettes mixed dry, but has a large influence upon the strength of sand mortar. It may be suggested also that to make by this method briquettes which are firm enough to handle immediately the cement must be mixed very

dry—too dry for the best results; with sand mortars it will be very difficult to produce solid cakes by this method.

The experience of the author in experimenting with various appliances for moulding briquettes shows that quite uniform results may be obtained from briquettes moulded under a single application of a steady pressure.

This method may be applied much more rapidly than the hammer method, with about as good results, and render the results of different operators much more concordant than can be obtained by hand-work, although the variations from the mean in the work of a single observer may be as great or greater than in the hand-work.

Briquettes of neat cement, machine-mixed, and moulded under a pressure of about 500 lbs., upon the surface of the briquette, give good results when the averages of different men are compared, and small variations in pressure are not important in the results.

For sand mortar, one part cement to three parts sand, a pressure of 1000 to 1500 lbs. is desirable to sufficiently compact the mortar to form homogeneous briquettes and give uniformity in the results.

To obtain the best results the mortar should be gauged to such a consistency that the water begins to ooze out under the pressure, the cakes being reduced to a semi-plastic condition, and becoming too soft to handle before setting.

An apparatus for making briquettes by this method is easily arranged, but no satisfactory method of manipulating the briquettes so as to produce them with reasonable

quickness has been devised in any of the machines proposed for this purpose.

It is quite as important to eliminate the personal element from the gauging as from the moulding of briquettes. For this purpose several appliances have been tried.

The *Jig mixer* is an apparatus in which the materials are placed in cups with covers clamped on, and shaken rapidly up and down. It has been tried in a number of places, but has usually been found quite unsatisfactory in practice. It is difficult to make a satisfactory mixture by this method, and the result depends very much upon the rapidity of operation.

The *Faija mixer* was designed and first used by Mr. Faija in England. It is shown in Fig. 13, as made by Riehle Bros. Testing Machine Company, of Philadelphia, and consists of a cylindrical pan in which a mixer, formed of four curved blades, revolves both on its own axis and about that of the pan. This arrangement gives fairly good results in use.

Fig. 14 shows an arrangement used by the author in the laboratory of the College of Civil Engineering at Cornell University.

In this apparatus the cylinder containing the materials is closed, thus avoiding the dust, which is very disagreeable with the open pan. The cover revolves about the axis of the cylinder, and the gear is placed outside to remove any danger of it becoming clogged. The mixer is formed of vertical rods held by a horizontal arm, and revolves about the axis of the cylinder and also about the middle point of the arm.

To devise any system of making briquettes by hand

which will secure uniformity in the work of different men seems hopeless. If such uniformity is to be secured, it must be by the use of automatic appliances.

The appliances thus far proposed, however, while capable of securing good results under careful manipulation, are too slow or clumsy in operation and require too careful management to make them desirable for

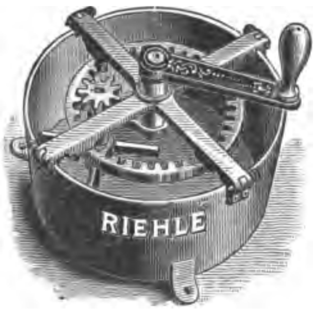

FIG. 13.

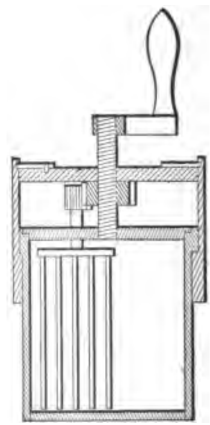

FIG. 14.

general use. The American Society Committee in 1904 report as follows upon this matter:

"The Committee, after investigation of the various mechanical mixing-machines, has decided not to recommend any machine that has thus far been devised, for the following reasons:

"(1) The tendency of most cement is to 'ball up' in the machine, thereby preventing the working of it into a homogeneous paste; (2) there are no means of ascertaining when the mixing is complete without stopping the

machine, and (3) the difficulty of keeping the machine clean."

ART. 47. TENSILE TESTS.

The test for tensile strength is commonly made by placing the briquette in a pair of clips which catch its ends and are attached to a machine by which the load necessary to break the briquette may be weighed. In order to secure uniform results it is necessary that the stress shall be so applied as to bring the tension axially

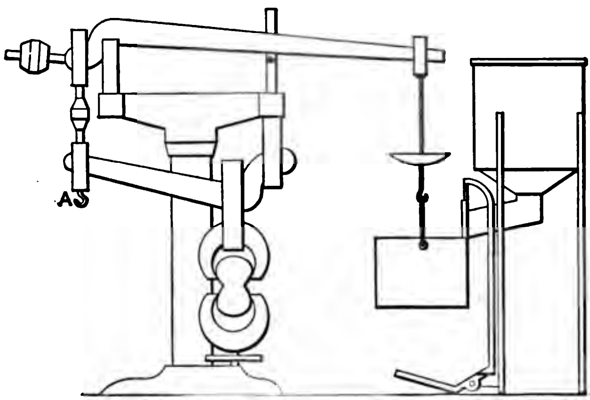

FIG. 15.

upon the small section of the briquette, and also that the rate of application of the load shall be always the same.

There are various types of testing-machines in use, and it seems unnecessary to enter into any detailed description of them here.

The *Michaelis* machine, shown in Fig. 15, consists of a set of levers suspended from the framework carrying at one end the clips which hold the specimen and at the

other a bucket into which shot may be run to apply the load, the shot being automatically shut off when the specimen breaks.

The *Fairbanks Machine* is practically the same as that of Michaelis. In the Fairbanks machine the shot is weighed and the stress determined by the same beam used in breaking the specimen, the bucket being hung at the other end of the beam from that used in breaking the specimen, and the weight found by means of a sliding weight, the beam being graduated to read stress upon the briquette.

The *Riehlé Machine*, shown in Fig. 16, is an ordinary lever machine in which the load is brought upon the specimen by means of the lower hand-wheel, while the weight is moved along the scale-beam by the upper hand-wheel. In testing a briquette both wheels must be operated simultaneously and the scale-beam be kept balanced.

The *Olsen Machine*, shown in Fig. 17, is similar in character to the above, but differs somewhat in detail. This machine has been modified by Prof. Porter in one constructed for Lafayette College, by adding a second lever below the clips, through which the stress is applied by means of water flowing into a bucket attached to its end. The stress is measured by the weight sliding upon the upper scale-beam as in the ordinary machine, but the weight is moved automatically by means of an electric contact at the end of the beam.

Various modifications of these machines and others of more complicated type are frequently employed. Nearly any of the machines in common use may give good results in practice. In selecting a machine, however, those are

to be preferred in which the load may be automatically applied at a uniform rate. The attainment of a constant rate of application with a hand-machine is a matter of considerable difficulty.

FIG. 16.

In order that the stress upon the briquette shall be axial, care must be exercised in properly centring the briquette in the clips, and the form of the clip must be such that it shall not clamp or bind upon the head of the briquette, but may be free to adjust itself to an

even bearing. The surface of contact between the clip and briquette must be large enough to prevent the material of the briquette being crushed at the point of contact,

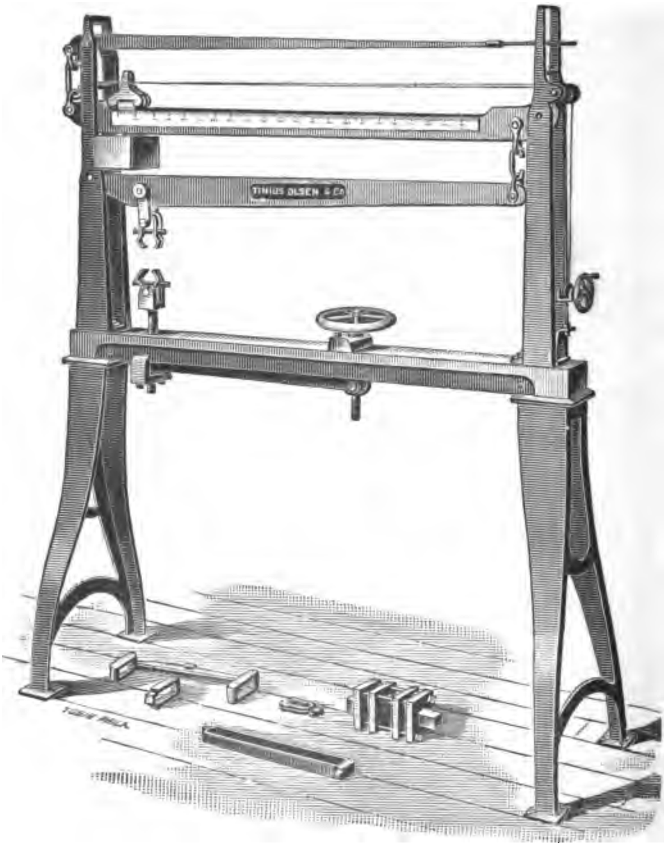

FIG. 17.

and yet as small as possible to admit of its more free self-adjustment. The suspension of the clips, as is usual, by conical bearings permits them to turn so as

to always transmit the stress in a right line between bearings.

Fig. 18 shows the form of clip which is used with the standard German briquette. As here given it is approved by the "Commission des Méthodes d'Essai des Matériaux de Construction," as giving very satisfactory results.

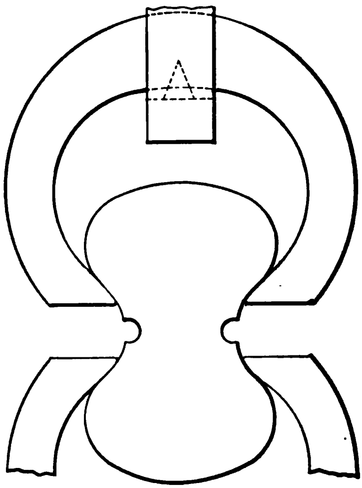

FIG. 18.

With the briquette used in the United States and England several forms have been used for clips. Fig. 19 shows the form adopted by the Committee of the American Society of Civil Engineers in 1885. This form does not offer sufficient bearing-surface for good results, as the briquette is likely to break on account of the crushing of the surface of the briquette at the point of contact.

The form shown in Fig. 20 has been much used, but has the disadvantage of clamping the head of the briquette too closely, and unless great care is used may cause the

briquette to break by twisting, thus giving irregular results. When the break occurs through the crushing of the material the fracture usually extends from one of the points of contact irregularly to the small section, but a break due to twisting may often be a centre break, and the irregularity show only in the results.

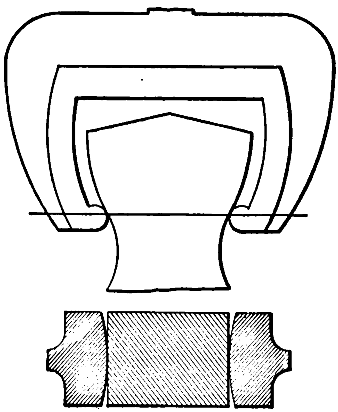

FIG. 19.

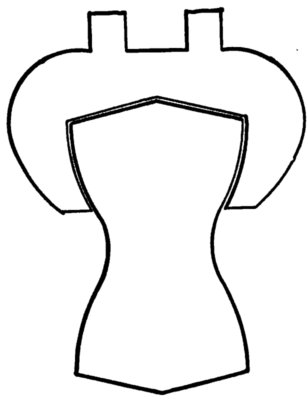

FIG. 20.

The form of clip shown in Fig. 21 is recommended by the Committee of the American Society of Civil Engineers in 1904. This form is a decided improvement over the older forms, but seems to give rather too small area of contaet between the briquette and clips for the best results. It avoids twisting the briquette and permits sttisfactory adjustment to axial stress.

In order to prevent crushing at the points of contact and to permit more free adjustment Mr. W. R. Cock has proposed * a rubber bearing, as shown in Fig. 22.

* *Engineering News*, Dec. 20, 1890.

The use of this clip undoubtedly increases to some extent the proportion of centre breaks and perhaps slightly raises the breaking strength, but its use requires considerable care and the rubber must be frequently renewed.

Various appliances have been proposed for the accurate centring of briquettes, or to prevent the more free adjustment of the clips to the direction of stress, by

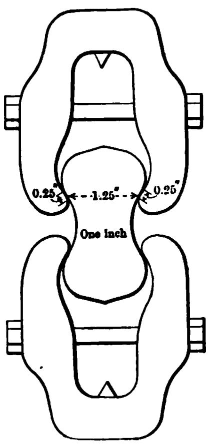

FIG. 21.

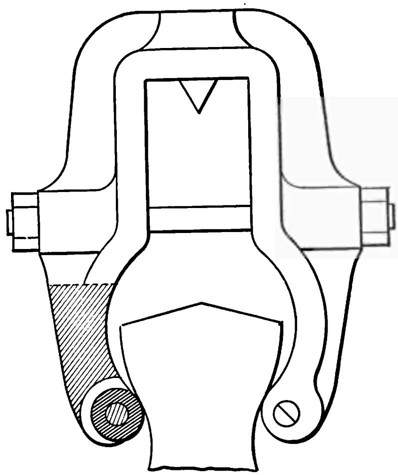

FIG. 22.

using a template for the exact placing of the briquette, or by hinging the clips at the upper corners. These arrangements do not, however, seem to be necessary.

The Committee of the American Society of Civil Engineers in 1904 made the following recommendations concerning tests for tensile strength:

"The tests may be made on any standard machine. A solid metal clip is recommended. This clip is to be

used without cushioning at the points of contact with the test specimen. The bearing at each point of contact should be ¼ inch wide, and the distance between the centers of contact on the same clips should be 1¼ inches.

"Test pieces should be broken as soon as they are removed from the water. Care should be observed in centring the briquette in the testing-machine, as cross-strains, produced by improper centring, tend to lower the breaking-strength. The load should not be applied too suddenly, as it may produce vibration, the shock from which often breaks the briquette before the ultimate strength is reached. Care must be taken that the clips and the sides of the briquettes be clean and free from grains of sand or dirt, which would prevent a good bearing. The load should be applied at the rate of 600 lbs. per minute. The average of the briquettes of each sample tested should be taken as the test, excluding any results which are manifestly faulty.

ART. 48. COMPRESSIVE TESTS.

The compressive strength of cement-mortar is much greater than its tensile strength, and as it does not seem to give a better indication of value, while more difficult of satisfactory determination, and also requires heavier apparatus, it is not usually employed as a test of quality in the acceptance of material. The compressive test is, however, valuable for purposes of comparison, and is desirable as an addition to the showing made by the tensile test. In the European experiment stations it is customary to test all cements under compression as well as tension.

For this test, as for tension, it is essential that a standard method be followed if comparable results are to be obtained. The size and shape of the specimen are of the greatest importance. The effect of compression is ordinarily to cause the material to spread laterally by pressing out the sides, failure usually occuring by shearing along surfaces inclined at about 30° with the vertical, leaving pyramidal or conical blocks at the middle.

When the specimen is small in height the resistance is greater per unit area than if it be higher, and for blocks similar in form the resistance increases with the size. Cubes are commonly employed for this purpose, but cylinders are sometimes preferred, on account of the greater ease with which homogeneous specimens may be prepared, and because of the liability of the corners of cubes to crack off under comparatively light pressure.

The common piece in Europe is a cube with edges 7 centimeters long, moulded under the hammer, and in testing it is required that the pressure be always exerted on two faces of the cube, that is, on the faces which are against the surface of the mould, in forming the block.

The German conference at Berlin, however, recommended the use of blocks 5 square centimeters in area, the same as the tensile specimens.

The French "Commission on Methods of Testing Materials" made the following recommendations:

"For tests of compressive strength the half-briquettes separated by tension are to be used. Each half-briquette to be crushed separately, and the sum of the two results taken as the strength of the specimen.

"In the absence of half-briquettes, cylinders 45 milli-

meters in diameter and 22 millimeters high may be used, made and conserved like the tensile briquettes.

"Those specimens which show visible irregularities or distortions are smoothed by lightly rubbing in the hand upon a stone surface."

"The testing apparatus should be so arranged that the stress may be continuously applied at such a rate as to crush the half-briquette in one or two minutes."

"For tests having for their object the comparison of mortar with other materials, it is provisionally recommended to employ the cube, with faces of 50 square centimeters area, placed upon one side. These tests will thus conform in a general way to the rules adopted for the other materials."

In the United States it is common to employ 2-inch cubes for this purpose, although some laboratories use cylinders of about the same area and somewhat greater height.

For making compressive tests of cement, any of the ordinary lever or hydraulic machines in common use, with a capacity of 40,000 to 50,000 lbs., is usually sufficient. It is desirable that the load be applied as uniformly as possible, as the result will be more or less affected by unsteadiness or shocks.

It has been proposed to employ punching tests instead of crushing the entire specimen. This method has been employed for a number of years in the laboratory at Teil, France. A punch five square centimeters in section (circular) is employed, and it is claimed that the results are more regular than those obtained by crushing the entire specimen, while requiring less force in the testing-machine. The "Commission des Méthodes d'Essai des

Matériaux," however, concluded that it presented no advantage over the ordinary test.

ART. 49. TRANSVERSE TESTS.

Tests of the strength of mortar under transverse loading are seldom employed as a measure of the quality of the material, but are frequently made with a view to determining the action of the material in service. Propositions have often been made to substitute the transverse for the tensile test in the reception of material. These suggestions have usually been based upon the simplicity of the test and of the apparatus with which it may be carried out. All that is necessary, after the bar is prepared, is the arrangement of a couple of knife-edges upon which the ends of the bar may be rested, and a third knife-edge to carry the weight brought upon the middle of the bar. The ordinary test by tension is, however, quite simple, and there seems to be little if any advantage in making a change, although the transverse test offers an equally effective means of determining quality. Much less is known as to what the transverse strength should be, and its use in specifications would need to be preceded by experiments to obtain proper values for the loads to be required, while the errors due to differences in making briquettes would exist the same in the one case as in the other.

Prof. Durand-Claye made a large number of tests to compare tensile and transverse strength for both neat cement and mortars in small test-pieces. He used bars 2 centimeters square and 12 centimeters long, and tension-pieces of the ordinary 5-square-centimeter sec-

tion, and found the results quite regular. The modulus of rupture per square centimeter, computed by the ordinary formula ($R = \frac{3}{2}\frac{Pl}{a^3}$, where P=load, l=length, and a^2=area of section), were found to average a little less than twice the unit stress for tension. The use of this formula in this instance is of course inexact, as it assumes the material to have the same coefficient of elasticity for tension as for compression, and to be strained only to the elastic limit. As all the specimens are of the same size, however, this is immaterial for purposes of comparison.

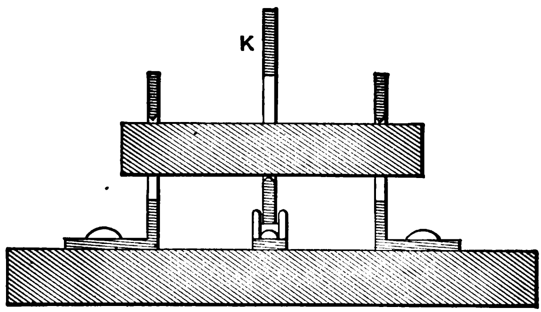

FIG. 24.

In making the transverse test the most common method has been to provide supports for the ends of the bar and hang weights directly upon its middle. Care should be exercised to guard against the crushing of the material under the knife-edges; a good plan is to use small plates of iron between the knife-edge and the surface of the briquette to distribute the load.

Where a tension-machine is in use, a transverse attachment is readily added, by which both tests may be made by the same machine. Fig. 24 shows such an attachment

as it is commonly used in Europe in connection with the Michaelis machine; the rod *K* is attached to the end of the lower lever in the machine (*A*, Fig. 15), thus receiving a less effect from the application of the load than the tension specimen.

In using small specimens for transverse tests it is found more difficult to handle the test pieces without injuring them, and, in general, if fairly accurate results are necessary, the tensile test is more easily handled.

RT. 50. FACTORS AFFECTING STRENGTH TESTS.

As already pointed out small differences in the manipulation or the surroundings of the material during the test may have an important influence upon the results of a test for strength of cement.

Temperature.—The effects of variations in temperature differ for different cements. In general, mixing at a low temperature of air and materials results in a greater strength than is obtained by mixing at a high temperature, the difference being greater for quick-setting materials. It is common to prescribe a temperature between 65° and 70° Fahr. for standard tests. Lowering this temperature to 40° or 45° will sometimes increase the strength on seven-day tests 20%, while increasing the temperature to 80° or 85° may correspondingly diminish the strength. In using some rather quick-acting materials, mixing with water at 100° will practically ruin the mortar.

On the other hand, within the limits of ordinary air temperatures, briquettes kept at high temperatures during the early period of hardening usually show greater strength than those kept at low temperatures. There is,

likewise, a marked difference between different cements in this particular. Briquettes kept in water are usually more affected by varying temperatures than those kept in air.

Consistency.—The quantity of water to be used in making briquettes is determined for standard tests by finding the quantity necessary to give normal consistency, as described in Art. 40. Variations in the quantity of water may very materially affect the strength upon short-time tests. As a rule the use of a comparatively dry mixture, provided the paste be throroughly mixed and well compacted in the moulds, gives higher results in short-time strength tests than if a wet mixture be employed. This difference may largely disappear in tests made after longer periods of time. With some quick-acting materials the quantity of water given by the normal consistency test is abnormally large, and changes materially the action of the cement from what it would be with less water. In one instance a cement mixed with about 25% water gives a rather dry paste, setting in ten or twelve minutes, and giving fairly good strengths at one and seven days. For normal consistency, this cement requires over 40% of water, and mixed with this quantity, sets in about six or seven hours, and has no strength at one day and very little in seven days. After two months both samples show good strength. Where such materials are to be used some modification of method is desirable.

Moisture.—Cement briquettes kept damp during setting and the early period of hardening show much greater strength than those kept in dry air. It is usual to place the briquettes in a damp-closet for the first 24 hours

after they are made, and then (for standard tests) to immerse them in water at 65 to 70° Fahr. until they are to be tested. In many instances, where a damp-closet is not available, the briquettes are covered with damp cloths during the first period. This requires considerable care to insure good results, as unequal or premature drying of the cloths may materially affect the results of the test.

The effects of variations in the moisture conditions are not the same for all cements, some natural cements acting quite differently from the usual rule, and not requiring a moist atmosphere for the development of early strength. Where very long time tests are made the greatest strength is usually developed by taking the briquettes from the water and keeping dry during the later period.

Character of Water of Immersion.—The nature of the water in which briquettes are kept has been found in some instances to materially affect their strength. A difference of 40% has been obtained between briquettes in running water and in water which had stood in the tanks for a long period without change. The water of immersion should be frequently renewed when running water is not available.

The presence of carbon dioxide in the water seems necessary to proper hardening of the mortar. In distilled water the briquettes will disintegrate. Nearly any fresh natural water which has been well aerated will give good results.

Art. 51. Interpretation of Results.

The test for strength is regarded as a measure of the value of a cement as showing the possession of the active elements. There are, however, different elements which act at different rates, and it is unwise to classify cements according to strength alone. The tensile strength developed by cement in a test extending over a short period of time is not necessarily an indication of the strength that may be attained by it during a longer period, unless the normal action of the particular material be known. That which is strongest at first may not continue to be the strongest.

The development of good strength soon after the use of the mortar is a desirable attribute in most engineering work, and the probability of the material being good is greater where it shows a fair early strength, and therefore it is usually wise to specify that the cement shall develop a fairly good strength on a short-time test, but there is no object in requiring extremely high values.

Mr. Faija recommends that the gain in strength between the 7- and 28-day periods be considered rather than the absolute early strength in determining the probable subsequent gain in strength. This is doubtless a better guide than the usual one, but it is not usually practicable to require tests extending over a period of 28 days, and in many instances it would be misleading, if comparison of different cements were attempted.

Prof. Unwin gives a formula for the strength at any period, $y=a+b(x-1)^n$, in which y is the strength at x weeks after mixing, a the strength at end of one week,

n a constant for the particular material to be determined by observations extending over considerable time, and b a constant to be determined from the strengths given by the sample at 1 week and 4 weeks after mixing. Prof. Unwin gives the value $n=1/3$ for Portland cement in general, and shows that the formula gives values well in accord with the results of tests in many instances. It is not, however, accurate for general use, as is shown by its failure when applied to many long-time tests.

The values to be required in specifications need to be modified, especially with the natural cements, to accord with the particular kind of cement to be used, and also with the practice of the laboratory.

Where large quantities of cement are regularly employed, and the same men continuously make the tests, it is a comparatively simple matter to conform the specifications to the work of the laboratory so as to get reliable indications of the value of the material. A very large portion of the testing for reception of material must, however, be done upon detached works, where temporary laboratories are to be used and inspectors employed for the occasion. In these cases it is a difficult matter to adopt a specification which shall give good results, unless the operator can himself first be calibrated.

The results of tests in the permanent laboratories usually give higher strength for the same material than would be obtained on an ordinary outside test, especially by a comparatively inexperienced man. It is not to be inferred, however, that the highest results are necessarily the outcome of the greatest skill. As a rule, the most expert and reliable operators get only moderate strength for the best material.

Lack of skill in conducting tests nearly always tells against the material tested, and good material may often be rejected because of inexperience in the inspector; but, on the other hand, it is a frequent trick of contractors having inferior material rejected on an ordinary test to send it to one of the laboratories known to obtain abnormally high strengths, and thus get results which seem to show error on the original test.

The American Society for Testing Materials has recommended the following as the range for minimum values in specifications for tensile strength of briquettes 1 square inch in section.

NATURAL CEMENT.

Age.	Neat Cement.	Strength.
24 hours in moist air		50–100 lbs.
7 days (1 day in moist air, 6 days in water)		100–200 "
28 days (1 " " " 27 " " ")		200–300 "
	One Part Cement, Three Parts Standard Sand.	
7 days (1 day in moist air, 6 days in water)		25– 75 "
28 days (1 " " " 27 " " ")		75–150 "

PORTLAND CEMENT.

Age.	Neat Cement.	Strength.
24 hours in moist air		150–200 lbs.
7 days (1 day in moist air, 6 days in water)		450–550 "
28 days (1 " " " 27 " " ")		550–650 "
	One Part Cement, Three Parts Sand.	
7 days (1 day in moist air, 6 days in water)		150–200 "
28 days (1 " " " 27 " " ")		200–300 "

In specifications it is usually desirable to require tests showing a fair degree of strength rather than very high values. The latter are if anything less likely to give good material and unnecessarily limit competition.

CHAPTER VII.

TESTS FOR SOUNDNESS.

ART. 52. ORDINARY TESTS.

SOUNDNESS is the most important quality of a cement, as it means the power of the cement to resist the disintegrating influences of the atmosphere or water in which it may be placed. Unsoundness in cement may vary greatly in degree, and show itself quite differently in different material. Cement in which the unsoundness is very pronounced is apt to become distorted and cracked after a few days, when small cakes are placed in water. Those in which the disintegrating action is slower may not show any visible change of form, but after weeks or months gradually lose coherence and soften until entirely disintegrated.

The method in common use for testing unsoundness is to make small cakes or pats of neat cement, usually about 3 or 4 inches in diameter and 1/2 inch thick, upon a plate of glass, and keep them in air or water for a few days, carefully watching them to see if they show any signs of distortion or surface cracks, which may indicate a tendency to disintegration.

The German standard specifications require that the

cakes for this test shall be 1.5 centimeters thick at the centre and have thin edges. These cakes are placed in water 24 hours after they are made, or at least not until they are firmly set, and observations are continued over a period of 28 days, when, if no cracks or distortions appear, the cement is considered sound.

"The cakes, especially those of slow-setting cement, must be protected against draughts and sunshine until their final setting. This is best accomplished by keeping them in a covered box lined with zinc or under wet cloths. In this manner the formation of heat cracks is avoided, which are generally formed in the centre of the cake, and may be taken by an inexperienced person for cracks formed by blowing."

The French Commission upon Methods of Testing Materials recommend both a pat test and test of the amount of swelling which takes place in the mortar, as follows:

"*Cold Tests.*—(*a*) For this test the cement paste is formed into a pat about 10 centimeters in diameter and 2 centimeters thick, made thin at the edges.

"Immediately after being made the specimens intended for tests in water are immersed in the same conditions as the briquettes used for tensile tests.

"The specimens intended for use in the air are at once exposed to the conditions indicated for briquettes."

"The condition of the specimens is observed at the same periods of time employed in making tensile tests (7 days, 28 days, 3 months, 6 months, 1 year, etc.).

"(*b*) To measure the increase in volume of the mortar of neat cement after prolonged immersion in cold water, a bar of cement is employed 80 centimeters in length and

12 millimeters square, placed vertically in a glass tube 25 millimeters in diameter, which is then filled with water."

"The elongation is measured by the motion upon an arc of a needle moved by a rod resting upon the upper extremity of the bar of mortar." (See Fig. 25.)

The method of testing by measuring the variation in length is also used to some extent in Germany. Methods of conducting this test are described in Art. 53.

It is important in testing soundness in this manner that the tests should be continued over as long a period as possible, and many cases of unsoundness are not discovered with a 28-day test. Instances have been observed in which mortar in the form of 2-inch cubes has completely disintegrated within two years, where incipient checking was not observable for three months in a small cake test. The most common and dangerous cases of unsoundness are probably discovered by the ordinary tests. It may be observed, however, that the fact that disintegration of mortar is not oftener observed in large constructions is probably due more to the general good quality of the cement supplied by the best makers, and to the frequent stability of work regardless of the nature of the mortar, than to the efficiency of the test for soundness.

The quantity of water to be used in mixing mortar for tests of soundness is about the same as that used for tests of strength, although a variation in the quantity within small limits does not seem to materially influence the results. Care must be taken that the cakes be kept moist during setting and previous to immersion, in order that they may be free from drying cracks. On this account the French commission con-

sider it preferable to immerse the specimens immediately after mixing, without waiting for the mortar to set. Some natural cements do not stand immediate immersion although apparently quite sound in water if first allowed to set in air.

When mortar is to be used in sea-water, the pats of cement are placed in water of the same character, and as nearly as possible corresponding to the conditions of practice.

Practically, however, the action of sea-water is so slow that the test is comparatively useless. M. Alexandre found * that the first indication of disintegration may not be shown for several months or perhaps years. He also found that the action in the laboratory did not always accord with that in the work. This was probably due to failures occurring because of the method of employing the mortar, when the cement was not defective.

Tests are sometimes made of mortar to be used in sea-water by causing the water to filter through the block of mortar under pressure. This test is made in France by employing the standard cubes used in compression, which are arranged and submitted to filtration as in the test for permeability (see Art. 67). These blocks are afterward crushed, and their strengths compared with those kept under normal conditions.

ART. 53. MEASUREMENT OF EXPANSION.

Unsoundness in cement is doubtless for the most part due to the presence of expansive elements, the action of which subsequent to the setting of the cement

* Annales des Ponts et Chaussées, Sept. 1890, p. 131.

produces internal forces, tending to disrupt the mass of mortar and usually causing an increase in its volume. The various tests for soundness have for their object the determination of the presence of these expansives, which may be indicated either by the distortion and cracking of the mortar when present in sufficient quantity, or bv a simple increase in volume without visible distortion when present in less quantity, or when more finely divided and uniformly distributed through the mass.

As a more efficient and accurate method of determining the presence of expansives than is afforded by the observation of thin pats of mortar, various appliances have been devised for the purpose of measuring directly the increase of volume of a block of mortar.

The Long-bar Apparatus.—The first apparatus for the purpose of measuring change of dimensions was devised by MM. Durand-Claye and Debray. It has been in use for a number of years in France, and was recommended for use in cold tests by the French Commission on Methods of Testing Materials (see Art. 52). This apparatus is shown in Fig. 25. The test is made upon bars 80 centimeters long and 12 millimeters square in section. The moulds in which these bars are formed consist of iron rods considerably longer than the bars to be formed, and of section 30 by 12 millimeters, laid flat upon a table, held apart at the ends by blocks of the same section as the cement bar, and prevented from spreading by clamps at the ends.

In making the test, the bar of cement is placed in a vertical glass tube 80 centimeters long and 23 millimeters in diameter, closed at the bottom and filled with the water, to the action of which the mortar is to be exposed.

To the top of the glass tube is fixed a ring carrying on one side an arc and on the other a rod, to which is hinged a needle, which travels upon the arc, being actuated by a rod resting upon the top of the cement bar. The extension of the cement bar is thus multiplied by 10

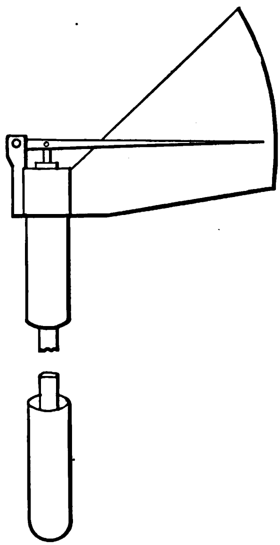

FIG. 25.

in the reading on the arc, which may be graduated, and the successive positions of the needle read from the scale, or it may be covered with blank paper, and have the positions of the needle-point marked and afterward measured. This method requires much care in manipulation, both in making the bars and in handling them in the test.

Bauschinger's Caliper Apparatus. — This apparatus, designed by Prof. Bauschinger and used in the German and Swiss laboratories, is an arrangement for measur-

ing the change of length of a short bar. It is shown in Fig. 26.

The bars used in the test are about 100 millimeters in length and 5 square centimeters in section.

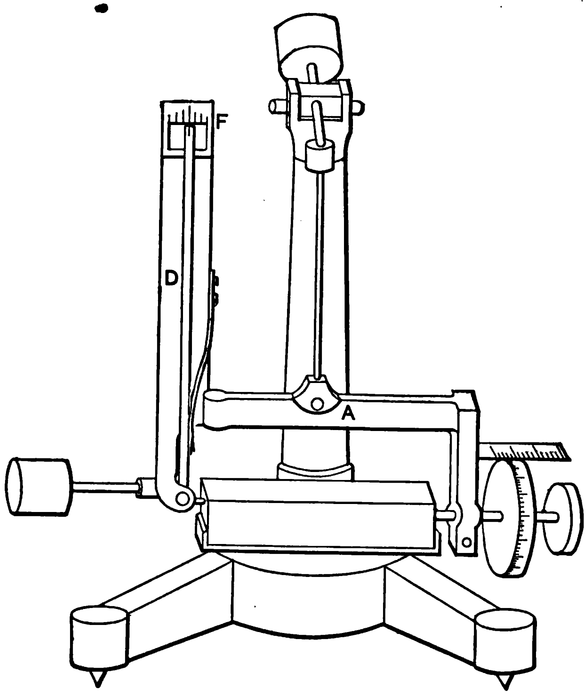

FIG. 26.

They are moulded with square cavities in the ends of the bars, in which are set small plates containing centres, to form bearings for the points of the micrometer-screw. The change in length may be measured to 1/200 millimeter.

The measuring apparatus is suspended by a rod from

a bar pivoted upon the top of the standard and balanced by counterweights so as to hang level. It consists of the caliper bar *A*, one end of which carries a micrometer-screw, reading to 1/200 millimeter, and the other end, a vertical bar at the bottom of which is hinged the needle *D*. The lower end of the needle has a point which is pressed by a spring against the end of the specimen in taking a measurement. The pressure of the micrometer against the specimen is regulated by bringing the point of the needle to zero on the scale *F*. A small bar of metal encased in wood is used as a standard in calibrating the instrument, the length of the standard being known very accurately at a definite temperature.

Le Chatelier's Apparatus.—The apparatus of Prof. Le Chatelier is designed to measure the increase in circumference of a cylindrical block of mortar. This method is recommended by the French commission for use in making hot tests, and is said to have the advantage of being much more easily manipulated than the other methods. It has also been suggested that the increase in length for long bars may not be an accurate indication of the actual swelling, as there would be a tendency for the expansion to take lines of least resistance, and therefore the transverse swelling may be more than the longitudinal.

This apparatus is shown in Fig. 27. It is described by Prof. Le Chatelier as follows: * "A much more simple and yet sufficiently precise measurement of the expansion can be made by letting the cement harden in cylindrical moulds of a dimaeter equal to their height (for example

* Trans. Am. Inst. Mining Eng.

30 mm.), constructed of metal 0.5 mm. thick, slit along generatrix and provided on each side of the slit with two long needles (150 mm. for example), which serve to magnify any widening of the slit. The widening is equal to the enlargement, not of the diameter, but of the circumference of the cylinder of cement. Very slow-setting cements or limes, the water of which would evaporate or drain away in air, it is indispensable to immerse as soon

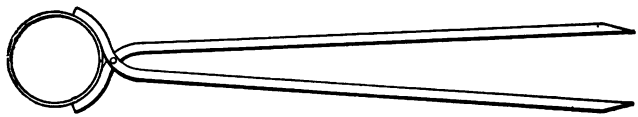

FIG. 27.

as moulded, without waiting for them to set. The immersion in water of a porus mass filled with air may sometimes, by reason of capillary phenomena, give rise to a certain expansion, and even to more or less disintegration if the hardness be insufficient. During the moulding and until the setting has taken place the mould should be kept firm by means of a suitable holder, which is removed after setting and before the measurements are begun.

"For products of good quality, the distance between the points of the needles does not attain 1 mm. in 28 days from the time of the end of setting. This test for invariability of volume, when made cold, has but little interest, since it detects only exceptionably bad products."

Art. 54. Accelerated Tests.

The fact that many cases of unsoundness in cement are not shown by the ordinary tests when extended over a short period of time has long been recognized, and many efforts have been made to find some means of determining with accuracy and within a reasonable time whether the material be reliable. The difficulty of this with a material of so variable a nature, and in which failure may be due to so many and so diverse causes, is self-evident. Each test must be directed to the determination of the presence of some particular cause of unsoundness, and all of them seem, when indiscriminately applied to all cements, to meet material which will not pass them, although of good quality, and to which they are evidently inapplicable.

Nearly all of these tests are directed to the detection of the so-called expansives, and most of them attempt to accelerate the chemical action, which causes the swelling and disintegration, by the action of heat. Some of the heat tests have proven fairly successful in use, although none have been extensively employed as tests for the reception of material.

Hot tests were first suggested by Dr. Michaelis, who proposed the use of heat to advance the hardening of cement, with a view to determining, from the strength gained in a short time in hot water, that which would result in a longer period under normal conditions. From the first experiments in this direction it appeared that the results obtained in from 1 to 7 days in hot water might bear a definite relation to those obtained in much longer

periods at ordinary temperatures. Later experiments showed, however, that while this might be true of a limited class of materials, as the composition is varied the effect of heat upon the strength also varies in a marked degree, some cement even showing a loss of strength in hot as compared with cold water.

In a series of tests made by M. Deval it was found that the addition of a small percentage of quicklime to a good Portland cement caused the cement to attain less strength when kept in hot than in cold water, and Prof. Le Chatelier proposed to utilize this discovery for detecting the presence of free lime. He suggested the use of briquettes of 1 to 3 mortar, and the comparison of the strengths of briquettes conserved for 3 and 7 days in water at 80° C. with those kept for 7 and 28 days in water at ordinary temperatures; the cements of good quality to show a strength a least equal in hot to that attained in cold water.

It is to be observed in considering this test that there are some good cements which give less strength hot than cold when of normal quality. M. Alexandre found that cements rich in aluminates behave in this manner. There are also certain cements which give high tests in hot water notwithstanding the presence of appreciable quantities of expansives. These are apparently silicious cements of low hydraulic index, in which the free lime while rendering the cement unsound does not cause it to lose strength in hot water during the short period of the test.

There are several methods of testing the soundness of cement by the aid of heat, which have come more or less into use, and have in many instances given satis-

factory results. These all aim at the detection of the presence of expansives through accelerating their action by heat, and then observing the deformations or measuring the expansion as in the corresponding cold tests. Descriptions of these tests are given in the following articles.

Art. 55. Kiln Test.

This test was originated by Dr. Bohmé, and consists in exposing small cakes of the cement to heat in a drying oven for a definite period, and observing whether it cracks.

The specifications of the Association of German Cement Makers recommend this test as a means of forming an opinion quickly, but make the ordinary 28-day test decisive as to those cements which fail to pass the kiln test. In these specifications the kiln test is described as follows:

"For making the heat test, a stiff paste of neat cement and water is made, and from this cakes 8 cm. to 10 cm. in diameter and 1 cm. thick are formed on a smooth impermeable plate covered with blotting-paper. Two of these cakes, which are to be protected against drying, in order to prevent drying cracks, are placed after the lapse of twenty-four hours, or at least only after they have set, with their smooth surfaces on a metal plate and exposed for at least one hour to a temperature of from 110° C. to 120° C., until no more water escapes. For this purpose the drying closets in use in chemical laboratories may be utilized. If after this treatment the cakes show no edge cracks, the cement is to be considered in general of constant volume. If such cracks do appear, the cement is not to be condemned; but the results of the

decisive test with the cakes hardening on glass plates under water must be waited for. It must, however, be noticed that the heat test does not admit of a final conclusion as to the constancy of volume of those cements which contain more than 3 per cent of calcium sulphate (gypsum) or other sulphur combinations."

This test is considered by some authorities to be of value for cements to be used in the air. It differs very radically, however, from the way the material is used in practice, as it effects the complete drying out of the mortar. In many instances also it is very difficult to interpret, in consequence of the loss of cohesive strength due to drying, where no distortions appear. The effect of the withdrawal of the water necessary to the proper hardening of the mortar may vary as the rapidity of action of the material varies.

The kiln test has sometimes been modified by using a moist atmosphere in place of dry air. A pan of water is placed in the oven under the specimens; the evaporation serving to keep the air saturated with moisture. Prof. Tetmajer used this method in a series of comparative tests and found it to give results similar to those of his boiling test, but somewhat less effective. His method was as follows: "The specimens are placed on a support in the oven, on the bottom of which are several millimeters of water. The heat is gradually applied so as to evaporate all the water in three to six hours,—first that which is on the bottom of the oven, then that which has been absorbed by the mortar. Until the water is entirely evaporated the temperature remains at about 95° C. The heating is continued a half-hour after the disengagement of the vapor ceases, in such manner as to raise the tem-

perature in the oven to 120° C. Under these conditions the interior of the briquette will reach but little above 100° C.

"It should be remarked that by this method it is difficult to render the results comparable. It is not possible to make the duration of heat exactly the same for all the specimens, and after the evaporation of the water the heat in the bottom is much greater than at the top of the oven."

Flame Test.—A dry-heat test has been proposed and is sometimes made in Europe, by making a ball of the cement paste about two inches in diameter and placing it on a gauze in the flame of a gas-jet. The heat is gradually applied, so that at the end of an hour it reaches a temperature of about 90° C. The heat is then increased until the lower part of the ball becomes red-hot, after which it is cooled and examined for cracks. The results of this test are much like those of the dry-kiln test, and are usually difficult to interpret satisfactorily.

ART. 56. STEAM AND HOT-WATER TEST.

This test consists in subjecting cakes of cement, prepared in the ordinary manner, to the action of steam for three or four hours, then immersing in hot water for the remainder of twenty-four hours, and examining for cracks and distortions.

Mr. Faija, by whom this test was devised, uses it in his specifications for cement in England. He describes his method of conducting the test as follows:

"Briefly, it is a vessel containing water, the water being maintained at an even temperature of about 110° to 115° Fahr.; there is a cover to the vessel, so that above

the water there is a moist atmosphere which has a temperature of about 100° Fahr. The manner of carrying out the test is by making a pat, in the manner already described, on a small piece of glass; immediately the pat is gauged, it is placed on a rack in the upper part of the vessel, and is there acted upon the by warm vapor rising from the hot water; when the pat is set quite hard, it is taken off the rack and put bodily into the water, which, as has been already stated, is maintained at a temperature of 100° to 115° Fahr., and in the course of twenty-four hours it is taken out and examined, and if found then to be quite hard and firmly attached to the glass, the cement may be at once pronounced sound and perfectly safe to use; if, however, the pat has come off the glass and shows cracks or friability on the edges, or is much curved on the under side, it may at once be decided that the cement in its present condition is not fit for use."

Mr. Faija prefers the temperature given above, but other experimenters have seemed to get better results using a higher one. Prof. Tetmajer obtained fairly good results with a temperature just below the boiling-point—about 200° Fahr. He subjected the cakes to the action of steam for four hours, and hot water twenty hours, placing the cakes in the steam as soon as mixed.

Mr. Maclay modified this method of testing, and introduced it into the specifications of the Department of Docks, New York City. Four pats or cakes of cement prepared in the usual manner were used by Mr. Maclay for his tests, the conduct of which he describes as follows: *

* Transactions, American Society of Civil Engineers, vol. XXVII, p. 412.

"One of these pats is placed in a steam-bath, temperature 195° to 200° Fahr., as soon as it is made. The second pat is placed in the same steam-bath as soon as it is set hard, and can bear the 1-pound wire. The third pat is placed in the steam-bath after double the interval has elapsed that it took the pats to set hard, counting from the time of gauging. The fourth pat is placed in the steam-bath at the end of twenty-four hours.

"The first four pats are each kept in the steam-bath three hours, then immersed in water of a temperature of about 200° Fahr. for twenty-one hours each, when they are taken out and examined. To pass this test perfectly, all four pats, after being twenty-one hours in hot water, should upon examination show no swelling, cracks, nor distortions and should adhere to the glass plates. The latter requirement, while it obtains with some cements nearly free from uncombined lime, is not insisted upon, the cracking, swelling, and distortion of the pats being much the more important features of this test.

"In hot-water tests, where the cement is very objectionable from excess of free lime, improper burning, or other causes, the trouble generally shows itself in the cracking or distortion of all four pats. Where the cement is not so bad the cracking and swelling takes place in the first three pats only, and when the cement is still less objectionable only the first two pats crack or swell. The cracking or swelling of No. 1 pat alone can generally be disregarded.

"In every case of failure and rejection the cement should have been allowed to set hard in a normal temperature before subjecting it to a steam-bath."

It should be noted that the effect of exposing the

cement to steam before setting seems to differ with different material, depending perhaps upon the relative effects the heat may exercise upon the rate of setting and upon the action of the expansives. Where the rapidity of setting is greatly increased by the heat the severity of the test may be augmented by placing in the steam at once; but where the rate of setting is less affected, the heat may cause the action of the expansives to take place before the set, thus lessening the severity of the test. In most cases the result of the test is the same either way, but it seems fairer to permit the cement to set before submitting it to the test.

Mr. Maclay, however, in his specifications does not accept the results of the steam and hot-water test as conclusive in case of failure, but only considers it as cause for suspicion of the cement failing to pass it, and adds a further test for the purpose of apparently giving the the material one more chance. This test consists in testing the strength of briquettes conserved in hot water and comparing them with those kept cold.

"These briquettes are prepared and treated as follows: When making the briquettes for the ordinary cold-water tests, four additional sets of five each of neat cement, and four additional sets of mortar, one part cement and two parts sand, are prepared, and allowed to set twenty-one hours in moist air of about 60° Fahr. They are placed for three hours in a steam-bath about 195° Fahr., then immersed in water maintained at 200° Fahr., after which they are broken when two, three, four, and seven days old respectively, and the breakings compared with the normal breakings of briquettes seven and twenty-eight days old kept in cold water."

"The writer finds, in a general way, that the averages of the breakings of hot-water briquettes of pure cement, four days old, are nearly as high as the normal seven-day breakings cold, and the hot-water seven-day breakings of the pure cement are nearly as high as the normal twenty-eight-day breakings cold, where the cement is of good quality. Where the cement is poor, and the pats show cracking and distortion, there is generally a remarkable falling off in the strength of the hot-water briquettes from the above comparison., and one system can therefore be used as a check on the other."

This is practically the same test mentioned in Art. 54, as proposed by M. Le Chatelier. Its use in this manner is recommended by M. Candlot:

"The cements which contain free lime show less resistance in hot water than in cold. The cements of good quality in hot water show resistances equal to or greater than those in cold. Cements properly proportioned and homogeneous, but not completely burned, give, in this test, satisfactory results."

As already pointed out, however, the relative strengths hot and cold do not depend altogether upon the presence of expansives, and it is questionable if this method is as accurate as that it is designed to check. Some unsound materials certainly give high results in the measurements of the strength of briquettes conserved hot, while there seems to be no authentic instance of any unsound cement being accepted on the steam and hot-water test, although good cement may perhaps be condemned.

ART. 57. BOILING TEST.

The boiling test, which is very similar in effect to that by steam and hot water, was first suggested by Prof. Tetmajer of Zurich. It consists in placing the mortar to be tested in cold water, and then gradually raising the temperature of the water to boiling. Prof. Tetmajer's method is to place the pats in cold water immediately after gauging, raise the temperature to boiling in about an hour, continue boiling for three hours, and then examine the pats for checking and softening.

This method seems rather more severe in its effects upon the mortar than the other hot tests, although in general differing but little from the steam and hot-water test when a boiling temperature is employed in that test; the action, however, seems to be more energetic, and less time is required to arrive at the same results.

It seems desirable in using the boiling test to permit the cement to set before subjecting it to the test, as giving a more reliable indication of value. The results of the test are in most cases practically the same whether the cement has previously set or not. When cement is subjected to the boiling test before setting takes place it is necessary to exercise much care in the manipulation of the test to avoid any disturbance of the mortar through the motion of the water when heated. The results of the tests also depend somewhat upon the rate of setting of the material, and upon the influence of heat upon the rate of setting. With quick-setting cements this action is unimportant, but with those very slow the heat may cause the action of the expansives to take place in advance of them setting, or the ceent may romain soft until late

in the test, and appear to fail, in consequence of disturbance due to the ebullition of the water.

Prof. Tetmajer recommends for this, and in fact for all pat tests, that the cakes shall not be made with thin edges. His method is to roll a ball of the mortar, and then flatten the ball to the required thickness. The consistency of the mortar is determined by the requirement that is shall not crack in flattening or run at the edges. For tests in boiling water this seems desirable, but for pats to be used in the ordinary cold tests the thin edges are of advantage in expediting the results where unsoundness exists in the mortar.

The boiling test is frequently used in connection with apparatus for measuring expansion, in place of observing the distortions or cracks. The Bauschinger caliper apparatus is sometimes employed in this way, the bars being subjected to the boiling test, and the increase in length noted. The Le Chatelier apparatus (Fig. 27) is also usually employed in this manner. The French commission upon methods of testing materials recommend the use of the Le Chatelier apparatus for this purpose, in addition to the cold test given in Art. 52, as follows:

"*Hot Tests.*—For these tests cylindrical test-pieces are employed, 3 centimeters in diameter and 3 centimeters high, made in metal moulds 1/2 millimeter thick, cut on a generatrix, and carrying, one on each side of the slit, two needles, 15 centimeters long. The increase of the distance between the ends of the needles gives a measure of the swelling.

"The moulds as soon as they are filled are immersed in cold water. After an interval of not more than

twenty-four hours beyond the completion of the set the temperature of the water is gradually raised to 100° C. in from a quarter to half an hour. The temperature is maintained at 100° for six hours, and then it is allowed to cool before taking the final measurements."

"This method of testing is not applicable to quick-setting cements."

"The standard test for deformation is to be made upon neat cement of standard consistency."

The British Standard specificiations adopted in 1904 employ this test for Portland cement, conducted in the same manner as prescribed by the French specification above given. (See Appendix.)

The boiling test is more simple than the steam and hot-water test, and requires very little in the way of apparatus. It may readily be made anywhere without difficulty.

ART. 58. PRESSURE TEST.

Dr. Erdmenger has devised a high-pressure steam test for soundness. In this test the pats are allowed to harden for three days, and are then exposed to steam for six hours at a pressure of from 3 to 20 atmospheres. The originator has used this test for a number of years, and claims that it gives very satisfactory results, and that when properly carried out it enables a complete and rapid judgment to be formed on a cement containing magnesia.*

As with all accelerated tests, there has been much dispute as to the reliablity of this one, some authorities claiming that many of the best Portland cements fail

* Journal Society of Chemical Industry, vol. XII, p. 927.

under it, others considering it nearly infallible. It is a test requiring more extensive appliances for its execution than the other hot tests, and has not been so largely used as the others.

The test is executed both upon the neat cement and sand mortar, the severity of the test being greater upon the neat cements. Dr. Erdmenger claims that the best cements show no defect under this test at high pressures (forty atmospheres); that others may show defects at high pressures, although safe in practice (especially in the neat test), but they are not first quality; while cement which cannot stand the pressure test of about twelve atmospheres in the sand tests should be rejected as faulty.

Art. 59. American Standard Tests.

American Specifications commonly impose only the cold pat test for soundness, although in a number of instances the steam and hot-water test (Art. 56) is employed. In a few specifications the boiling test (Art. 57), with thin edged pats, is used.

The Canadian Society of Civil Engineers, in 1903, recommended the following:

(*a*) *Blowing test.*—Mortar pats of neat cement thoroughly worked are troweled upon carefully cleaned 5-inch by 2½-inch ground-glass plates. The pats shall be about ½ inch thick in the centre and worked off to sharp edges at the four sides. They shall be covered with a damp cloth and allowed to remain in the air until set, after which they shall be placed in vapor in a tank in which the water is heated to a temperature of 130° F. After remaining in the vapor six hours, including the time

of setting in air, they shall be immersed in the hot water and allowed to remain there for eighteen hours. After removal from the water the samples shall not be curled up, shall not have fine hair cracks, nor large expansion cracks, nor shall they be distorted. If separated from the glass, the samples shall break with a sharp, crisp ring.

The Committee of the American Society of Civil Engineers (in 1904) recommended the following:

"*Significance.*—The object is to develop those qualities which tend to destroy the strength and durability of a cement. As it is highly essential to determine such qualities at once, tests of this character are for the most part made in a very short time, and are known, therefore, as accelerated tests. Failure is revealed by cracking, checking, swelling, or disintegration, or all of these phenomena. A cement which remains perfectly sound is said to be of constant volume.

"*Methods.*—Tests for constancy of volume are divided into two classes: (1) normal tests, or those made in either air or water maintained at about 21° C. (70° F.), and (2) accelerated tests, or those made in air, steam, or water at a temperature of 45° C. (115° F.) and upward. The test pieces should be allowed to remain twenty-four hours in moist air before immersion in water or steam, or preservation in air.

"For these tests, pats, about 7½ cm. (2.95 inches) in diameter, 1¼ cm. (0.49 inch) thick at the centre, and tapering to a thin edge, should be made, upon a clean glass plate [about 10 cm. (3.94 inches) square], from cement paste of normal consistency.

"*Normal test.*—A pat is immersed in water maintained as near 210° C. (70° F.) as possible for twenty-eight days,

and observed at intervals; the pat should remain firm and hard and show no signs of cracking, distortion, or disintegration. A similar pat is maintained in air at ordinary temperature and observed at intervals.

"*Accelerated test.*—The pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel, for three hours.

"To pass these tests satisfactorily, the pats should remain firm and hard, and show no signs of cracking, distortion, or disintegration.

"Should the pat leave the plate, distortion may be detected best with a straight-edge applied to the surface which was in contact with the plate.

"In the present state of our knowledge it cannot be said that cement should necessarily be condemned simply for failure to pass the accelerated tests, nor can a cement be considered entirely satisfactory simply because it has passed these tests.

ART. 60. VALUE OF THE ACCELERATED TESTS.

The reliability of the various accelerated tests for determining the soundness of cement in use is a matter concerning which there is much dispute amongst authorities on the subject. These tests have not as yet come into general use, and considerable opposition has been developed to them, although in certain instances they are employed.

The question of adopting the accelerated tests was discussed by the Association of German Cement Manufacturers in 1891, and it was voted to adhere to the standard test already existing. It was also stated in

the report that experiment had not proved the inaccuracy of the standard test (the twenty-eight-day cold-pat test) and while the accelerated test may be useful to the manufacturers in determining the character of their cements, they should not be used by the consumer, with a view to forming a sound opinion on the constancy of volume.

The results of a number of experiments are also given in this discussion, showing that a number of cements which had not withstood the *kiln* test were sound when used under water at normal temperatures, or if placed in air after being kept moist for several days. It may be remarked also that most of the discussion seemed to refer mainly to the dry-heat test.

Some of the leading German cement experts, however, are strong advocates of the use of heat tests. Dr. Michaelis expressed his approval of them, and stated that he had experimented with and used them satisfactorily for a number of years at the Charlottenburg experiment station. Dr. Erdmenger also declares that experience has shown the high-pressure-steam test to give an accurate determination of the permanence of volume of the material. He states that most of the best German cements have stood this test up to a pressure of forty atmospheres for sand mortars and several for neat cement, the best of them showing no defect whatever; and he thinks there is no ground for the statement that many good cements will not pass the test.

Prof. Bauschinger found that cements which had given good results in the ordinary 28-day test, and also upon the cold-pat test for a year, failed when formed into prisms of 1 to 3 mortar for testing in the Bauschinger caliper apparatus. Expansion was detected in six months

by measurement, and afterward became visible to the naked eye.

The German Conference upon Methods of Testing* recommend the continuance of the present practice (the kiln test for quick determinations and the 28-day cold-pat test as decisive), but they state that "the boiling test may undoubtedly be considered as the most conclusive and rapid test for the determination of constancy of volume of Portland cement, of slag cement, and of trass," and refer a particular test to the sub-committee for further examination and report.

The French Commission upon Methods of Testing† recommend the use of the boiling test as the best method of arriving at a quick determination of the permanence of volume for Portland cement, the amount of the increase in volume to be measured directly, instead of simply observing the effect upon a small pat.

In England the steam and hot-water test has been introduced by Mr. Faija, using a low temperature; while in the United States the same test is employed in the specifications of the New York Department of Docks, using temperature near boiling. In some instances the boiling test has also been used in the United States by manufacturers in the study of their product with very good results.

The advisability of adopting some form of accelerated

* Resolutions of the Conventions held at Munich, Dresden, Berlin, and Vienna, for the purpose of adopting uniform methods for testing materials, by J. Bauschinger; translated by O. M. Carter and E. A. Gieseler (Washington, 1896).

† Commission des Méthodes d'Essai des Matériaux de Construction; Rapport (Paris, 1894 and 1895).

test in ordinary specifications is still an open question, needing for its determination more accurate knowledge than is now available of the behavior of the various kinds of cement when subjected to such tests.

Numerous experiments have been made for the purpose of deciding the matter, the results of which differ so widely from each other as to involve the question in great confusion. Most of these experiments have been made by studying the action of heat upon the various ingredients to which unsoundness is usually attributed, and arguing from the results whether the hot test gives an accurate indication of the presence of these ingredients in the cement. The most common method has been to mix a small quantity of quicklime with a good Portland cement, and then observe the action of the test upon the mixture. This involves the assumption that certain percentages of free lime are sufficient to render the cement unsound. The results of tests made in this manner are also subject to much variation, due to the nature of the cement, its rapidity of action, and the quantity of free lime which may have been originally present in it.

These experiments have been of much value in showing the effect of the accelerated tests upon various substances, and in discovering the reasons for many of the apparently contradictory results with them. The question of the ultimate adoption of tests of this character must, however, be determined by a comparison of the results obtained by their use upon the material as found in market with the action of the same material in practical use. To this end experiments are desirable which shall systematically compare the results of accelerated test upon ordinary cements with the results of tests under normal

conditions extended over long periods of time. An extended series of experiments of this character has already been carried out by Prof. Tetmajer at Zurich,* and a smaller series upon material in use in the United States at the laboratory of the College of Civil Engineering at Cornell University.

A careful study of the available results of experiment seems to justify the following statements:

1. Small percentages of uncombined lime or magnesia in the cement are commonly detected by the use of the heat tests, and the same ingredients in sufficient quantity render the cement unsound in ordinary use.

2. Cement liable to change of volume when employed under normal conditions is almost invariably detected when submitted to the hot-water test. There seems to be no well-authenticated instance of failure to condemn really defective material.

3. Nearly, if not quite, all of the best brands of Portland cement, and many of natural cement, as found in market, readily meet the requirements of these tests, which therefore do not impose so severe limitations upon the choice of cement as is commonly supposed. With natural cement the results of these tests vary somewhat with the character of the cement, and the same tests do not seem to be universally applicable. This, however, is a matter which can only be determined by careful experiment upon each of the various classes of natural cement. Many of them bear the severe tests fully as well as the Portland.

---

* Methoden und Resultate der Prüfung hydraulischen Bindemittel (Zurich, 1893).

4. While these tests rarely, if ever, fail to detect an unsound cement, and most good cements readily pass them, there are occasional instances of cements condemned by the heat tests, which are not unsound when kept at normal temperatures in fresh water. These cements for the most part seem to fail if kept in dry air or are subjected to the action of sea-water. Apparently, a degree of unsoundness may exist which is sufficient to cause the change of volume to take place in a short time in hot water or in a longer time in dry air, while in cold water the action of the expansives takes place without injury to the mortar. This is shown by the fact that pats of mortar which had failed in the boiling test at the time of mixing, after being kept several months in cold water, and then subjected to the boiling test, were found to stand the test perfectly, showing that the action of the expansives must meanwhile have taken place. In several instances pats of cement acting in this manner were found to blow in dry air.

The unsoundness of cement condemned by the heat tests, when the mortar is to be kept submerged in fresh water, is therefore, in many instances at least, questionable. In the large series of tests made by Prof. Tetmajer, out of 139 samples of Portland cement 17 failed in the boiling test, all of which also failed in a long time in dry air, while only 2 were defective in long time in fresh cold water. In the tests made by the author, the percentage of failures to total number of samples is less than at Zurich, 5 in 53, and 3 of the 5 samples which were rejected by the hot test were later disintegrated when kept in cold fresh water.

5. The fineness of the cement has an important bear-

ing upon its behavior under the heat tests. All ordinary cement probably contains some small proportion of expansives, which in the finely ground material may become hydrated without injury to the mortar; but if the fine material be sifted out, and only the coarse particles employed in the test, the slower action in the larger particles may cause distortion and cracking to take place. Whether the same difference usually follows in cold water has not been satisfactorily determined.

6. Portland cement which contains free lime in sufficient quantity to cause it to swell in the hot test may frequently be made to pass that test by adding a small quantity of sulphate of lime. The action of this salt upon the setting of cement has already been discussed (Art. 21). The rules of the Association of German Cement Makers permit the addition of a small proportion of sulphate of lime for the purpose of regulating the rate of setting, and conclude that no injury is thereby caused to the cement.

The action of the sulphate of lime to correct the expansive action of free lime is but imperfectly known. The fact that it causes cement containing free lime to pass the hot tests is well known, but whether the corrective influence extends to the action of the expansives when the material is used under normal conditions has not as yet been satisfactorily determined.

The strongest objection that has been urged against the use of hot tests is that they fail to detect free lime in the presence of the calcium sulphate. The justice of this objection can only be decided by experiments extending over considerable periods of time to determine whether the material so passed is sound under

normal conditions. Doubtless for use in sea-water it would be necessary to limit the quantity of sulphuric acid.

The whole subject of hot tests must still be regarded as in the experimental stage, and further experiment is necessary to determine more fully the connection between the results of tests and the action of the cement in use.

Under present conditions it may be said that the presumption is fairly against the soundness of a cement failing to pass the hot-water test and in favor of that which succeeds in passing it; but variations in the cement and in the conditions under which it is employed may affect the results, and they cannot be relied upon with certainty for all material. Upon ordinary work to be kept in fresh water there is probably no considerable danger of unsoundness in the use of any good brand of cement, although failure sometimes occurs; but for the more important works, and particularly those to be subjected to the action of sea-water, it is reasonable to apply such tests as are likely to insure good material, even at the risk of excluding other good material.

Art. 61. Air-slaking.

Sometimes fresh cement, when first opened after being shipped, will, if tested at once, show an abnormally rapid rate of setting, and subsequently harden very slowly, so that on short-time tests very low tensile strength may be given. If, however, this cement be exposed to the air for a few days, it may resume its natural rate of setting,

and attain proper strength upon the tests. In some laboratories it is customary to thus expose cement to the air a short time before testing, and this process is termed *air-slaking*.

The propriety of air-slaking in testing cement is questioned by some engineers, upon the ground that the cement to be used in the work will not be treated in the same manner. In England it is customary to give such exposure to all cement to be used upon important work for at least ten days, but in the United States the cement is commonly used just as received from the manufacturer.

The general practice seems to favor air-slaking in testing, and probably a cement capable of regaining its normal condition in a few days' exposure will not endanger the work, even if used at once, but it would doubtless be better in using such cement to air-slake the whole before using. It may be remarked, however, that air-slaking does not ordinarily seem necessary. The cement commonly placed upon the market by the best makers does not need it. While it may be allowable to give the material the benefit of the operation, probably few instances of rejection would occur on account of its omission.

In many instances the effect of air-slaking a cement requiring it disappears with time; that is, the strength of the mortar after three or six months may be as great for that mixed before as for that mixed after air-slaking, although the difference of strength on a test extending over a few days is very considerable. This would indicate the necessity of air-slaking the whole of the material if early strength is to be developed in the work, although

the ultimate strength might perhaps be satisfactory either way.

If the cement blows or shows unsoundness on the first test, it should not be used without exposure, as it would indicate a degree of unsoundness likely to be serious, even though this also disappear in the second test.

The question is simply as to the quantity of the expansives which may be present without danger to the work in which it is used.

CHAPTER VIII.

SPECIAL TESTS.

ART. 62. TESTS OF ADHESIVE STRENGTH.

THE ability of cement mortar to firmly adhere to a surface with which it may be placed in contact is one of its most valuable properties and quite as important as the development of cohesive strength. Tests for adhesive strength are not commonly employed as a measure of the quality of the material, because of the uncertain character of the test and the difficulty of so conducting it as to make it a reliable indication of value. The adhesive properties of the cement are to a certain extent called into play in the tensile tests of sand mortar, and may be inferred from a comparison of neat and sand tests.

Adhesive strength is developed more slowly than that of cohesion. The difference between the two, which is usually considerable during the early period of hardening, is gradually lessened with time. This is illustrated in the greater time required for sand mortar than for neat cement to harden.

Experiments upon the adhesion of mortars to various substances are sometimes made, both for the purpose of comparing various cements or methods of use, and to study the relative effects of various kinds of surfaces.

Such experiments are quite desirable with a view to the extension of knowledge of this very important quality.

The common method of making this test is to prepare briquettes, of which one half are of neat cement or sand mortar of the ordinary form for tensile specimens, and the other half a block of stone, glass, or other material to be used, of the same section as the mould at its middle, and arranged to be held by a special clip in the testing-machine at the other.

In Germany and Switzerland the apparatus shown in Fig. 28 is employed. The testpiece is shown at *a*;

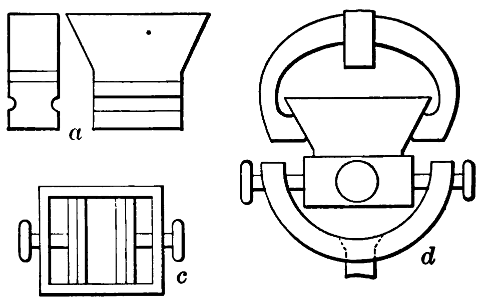

Fig. 28.

it has a section of 10 square centimeters—twice that of the standard tensile specimen. The mortar end is enlarged to a wedge shape to catch the upper clip of the testing-machine, while the other end is formed of a parallelopiped of marble or ground glass for standard tests, with a cylindrical groove cut in its side, which fits into a special clamp (shown at *c*). This clamp is held by screws, in the lower clip of the testing-machine, as shown at *d*. For forming the briquettes moulds

are used, in the bottom of which the blocks are placed and the mortar filled in on top.

In some laboratories blocks of marble have been used for standard tests in comparing different materials; but the large amount of labor involved in the preparation of the blocks, and the difficulty of getting always the same surface, has been a bar to the extension of this method. Ground glass has been more commonly employed, the same blocks being repeatedly used. Dr. Michaelis has also used for this purpose standard blocks of cement mortar, of the same form, which are easily prepared, and more uniform in material and surface.

The German Conference on Methods of Testing, before mentioned, did not define a standard test, but referred the matter to a sub-committee, with the recommendation that the German apparatus just described be utilized.

The French commission recommend the use of a briquette of double T form, suggested by M. Candlot. It is shown in Fig. 29. A mould is employed, made to the form of half the briquette, which is set down over the block to be used in forming the specimen.

The recommendations of the commission are as follows:

"A. To compare the adhesive strengths of cements, there is submitted to the tension test a briquette of the double T form, shown above, each of the materials to be studied constituting half of one of the specimens.

"B. Standard tests, intended to compare the adhesive strengths of various cements to the same material.

"(*a*) The standard adhesion-blocks are prepared of mortar composed of one part, by weight, of artificial Portland cement, passed through the sieve of 900 meshes

per square centimeter, and two parts of standard sand No. 3 (that passing a sieve of 1 mm. openings and retained upon one of 1/2 mm. openings). The mortar is gauged with 9 per cent water and strongly compressed in the moulds, in the bottom of which is placed a movable metallic block. The adhesion-blocks are immersed in fresh water after twenty-four hours, and kept thus until

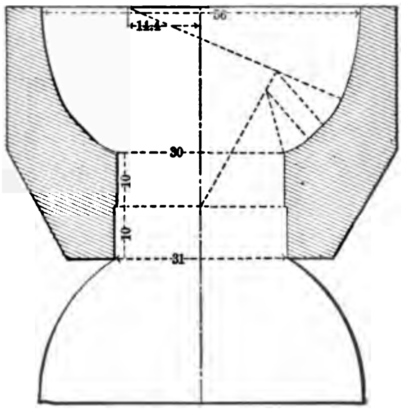

FIG. 29.

used, or at least for twenty-eight days. When they are to be utilized, they are dried and the surface is smoothed with emery paper.

"(*b*) The standard plastic mortar (see Art. 44) is employed for these tests, introduced by the pressure of the trowel into the moulds, placed in such manner that the standard adhesion-block forms the base. The briquette is removed from the mould when completely set."

"(*c*) The briquettes are tested in the same manner and at the same periods prescribed for tensile tests."

"C. Tests intended to compare the adhesive strength of a cement to various materials.

"(*a*) For these tests the same methods are adopted with the difference that the standard blocks are replaced by blocks formed of the various materials to be used. If the material can be moulded, the block may be made in the same way as the standard block. If the material is solid, a plate several millimeters thick may be formed having one face dressed. This is placed in the bottom of the mould and the block filled out with neat cement."

Art. 63. Chemical Analysis.

Chemical analysis is of very great value in the study of the properties of various cements, and is commonly employed by manufacturers in regulating the quality of their products. It is not commonly used for the purpose of determining the quality of a cement, and is not of much value as a test for the reception of material.

The quality of the cement depends not only upon the ingredients being properly proportioned, but also upon the state of combination of the ingredients, and this in turn depends upon the manipulation given the material in manufacture. Analysis shows the proportions of the various ingredients, but does not show their state of combination. The results of an analysis may show that the composition is such that a good cement may be made from the ingredients, but other tests are necessary to show whether it has been made. Chemical analysis may, however, prove a cement to be bad through its containing objectionable proportions of ingredients known

to be injurious. Thus the allowable percentage of sulphur compounds is sometimes prescribed for cement to be used in maritime work; in fresh water they may be unobjectionable. The expansive elements, free lime or free magnesia, cannot be detected by analysis, as their presence is not necessarily dependent upon the proportions of total lime or magnesia present.

The French specifications, devised by M. Guillain, for Portland cement reject those containing more than 1% of sulphuric acid, or sulphides in appreciable quantity; while those containing more than 4% of oxide of iron, or which give less than 44/100 for the ratio of the sum of the weights of silica and alumina to the weight of the lime are to be regarded with suspicion.

A large percentage of volatile elements in a cement indicate either insufficient burning or deterioration with age through exposure to the air.

M. Candlot states that a chemical analysis may be useful in showing the adulteration of cement, sometimes practised in Europe. Upon sifting the cement and separately analyzing the coarse and fine portions an unadulterated cement should show practically identical results for the two analyses. He also states that blast-furnace slag, which is a common adulteration in Portland cement, may sometimes be discovered by the odor of sulphuretted hydrogen upon treating it with hydrochloric acid.

The British Standard Specifications for Portland Cement adopted in 1904 recommend the following as a requirement for chemical composition: "There shall be no excess of lime, that is to say, the proportion of lime shall not be greater than is necessary to saturate silica

and alumina present. The percentage of insoluble residue shall not exceed 1.5 per cent; that of magnesia shall not exceed 3 per cent, and that of sulphuric anhydride shall not exceed 2.5 per cent."

The report of the Committee on Standard Specifications for Cement of the American Society for Testing Materials in 1904 recommend the following requirement for Portland cement: "The cement shall not contain more than 1.75 per cent of anhydrous sulphuric acid (SO_3), nor more than 4 per cent of magnesia (MgO)."

Method of Analysis.—The following method for the analysis of cement was recommended by committee on Uniformity in the Analysis of Materials for the Portland Cement Industry, of New York Section of the Society for Chemical Industry.*

"*Method suggested by Clifford Richardson, for the Analysis of Limestone, Raw Mixture, and Portland Cement, proposed for trial by the committee and modified in accordance with the suggestions of W. F. Hillebrand.*

"*Solution.*—One half gramme of the finely powdered substance is to be weighed out, and, if a limestone or unburned mixture, strongly ignited in a platinum crucible over the blast for fifteen minutes. It is then transferred to an evaporating-dish, preferably of platinum, for the sake of celerity in evaporation, covered with a watch-glass and 10 cc. of HCl, diluted with about 50 cc. of water, added. Digestion on the water-bath is allowed to go on for about 15 minutes, when the substance should

* Journal, Society for Chemical Industry, Jan. 15, 1902.

be entirely decomposed.* The cover-glass is then removed, washed, and the solution evaporated to dryness, as far as this may be possible on the bath.

"*Silica.*—The residue, without further heating, is treated at first with 5–10 cc. of strong HCl, and then with as much water as the dish will comfortably hold. The cover is then replaced and digestion allowed to go on for 10 minutes on the bath, after which the solution is filtered and the separated silica washed thoroughly with hot water. The filtrate is again evaporated to dryness, the residue, without further heating, taken up with acid and water and the small amount of silica it contains separated on another filter-paper. The papers containing the residue are transferred wet to a weighed platinum crucible, dried, ignited, first over a Bunsen until the carbon of the filter is completely consumed, and finally over the blast for 30 minutes and checked by a further blasting of 10 minutes or to constant weight. The silica, if great accuracy is desired, is treated in the crucible with about 10 cc. of HF and four drops of H_2SO_4, and evaporated over a low flame to complete dryness. The small residue is washed, finally blasted, cooled and weighed. The difference between this weight and the weight previously obtained gives the amount of silica.†

"*Al_2O_3 and Fe_2O_3.*—The filtrate about 250 cc., from the second evaporation for SiO_2, is made alkaline with

---

* If anything remains undecomposed it should be separated, fused with a little Na_2CO_3, dissolved, and added to the original solution.

† For ordinary control work in the plant laboratory this correction may, perhaps, be neglected; the double evaporation never.

NH_4OH, and boiled down to expel excess of NH_3, or until there is but a faint odor of it, and the precipitated iron and aluminium hydrates, after settling, are washed once by decantation and slightly on the filter. Setting aside the filtrate, the precipitate is dissolved in hot dilute HCl, the solution passing into the beaker in which the precipitation was made. The aluminium and iron are then reprecipitated by NH_4OH. The second precipitate is collected and washed on the same filter used in the first instance. The filter-paper, with the precipitate, is then placed in a weighed platinum crucible, the paper burned off and the precipitate ignited and finally blasted 10 minutes, with care to prevent reduction, cooled and weighed as Al_2O_3 and Fe_2O_3.*

"*Fe_2O_3*.—The combined iron and aluminium oxides are fused in a platinum crucible at a very low temperature with about 10 grammes of $KHSO_4$, the melt taken up with hot water and 25 cc. of dilute H_2SO_4. The clear solution is then digested on the steam-bath for about 10 minutes, and, if accuracy is desired, the small amount of silica is filtered out, weighed, and corrected by HF and H_2SO_4. The filtrate is reduced by hydrogen sulphide, boiling out the excess afterwards whilst passing CO_2 through the flask, and titrated with permanganate.†

"*CaO*.—To the combined filtrate from the Al_2O_3 and Fe_2O_3 precipitate a few drops of HN_4OH are added and the solution brought to boiling. To the boiling solution 10 cc. of a saturated solution of ammonium oxalate are

* This precipitate contains TiO_2, P_2O_5, MnO.

† In this way only is the influence of titanium to be avoided, and a correct result obtained for iron.

added, and the boiling continued until the precipitated CaC_2O_4 assumes a well-defined granular form. It is allowed to stand for 20 minutes, or until the precipitate has settled, and then filtered. The precipitate and filter are placed wet in a platinum crucible, and the paper burned off over a small flame of a Bunsen burner. It is then ignited, redissolved in HCl, and the solution made up to about 100 cc. with water. Ammonia is added in slight excess and the liquid is boiled. The small amount of Al_2O_3 which is separated is filtered out, weighed, and the amount added to that found in the first determination, when great accuracy is desired. The lime is then reprecipitated by ammonium oxalate, allowed to stand until settled, washed, weighed * as oxide by ignition and blasting to constant weight, or determined with standard permanganate.†

"*MgO.*—The combined filtrates from the calcium precipitates are acidified with HCl, and concentrated on the steam-bath to about 150 cc., 30 cc. of $Na(NH_4)HPO_4$ are added, and the solution transferred to a beaker and boiled for several minutes. It is then removed from the flame and cooled by placing the beaker in ice-water. After cooling, NH_4OH is added drop by drop, with constant stirring until the crystalline ammonium-magnesium ortho-phosphate begins to form, and then in slight excess, the stirring being continued for several minutes. It is then set aside for several hours in a cool atmosphere and filtered. The precipitate is redissolved in hot dilute

* The volume of wash-water should not be too large.

† The accuracy of this method admits of criticism, but its convenience and rapidity demand its insertion.

HCl, the solution made up to about 100 cc., 2 cc. of a saturated solution of $Na(NH_4)HPO_4$ added, and ammonia drop by drop, with constant stirring until the precipitate is again formed as described. It is then allowed to stand for about two hours, when it is filtered on paper or a Gooch crucible, cooled and weighed as $Mg_2P_2O_7$.

"*K_2O and Na_2O.*—For the determination of the alkalies, the well-known method of Prof. J. Lawrence Smith is to be followed, either with or without the addition of $CaCO_3$ with the NH_4Cl.

"*SO_3.*—One gramme of the cement is dissolved in 15 cc. of HCl, filtered and the residue washed thoroughly.*

"The solution is made up to 250 cc. in a beaker and boiled. To the boiling solution 10 cc. of a saturated solution of $BaCl_2$ are added slowly drop by drop from a pipette and the boiling continued until the precipitate is well formed. It is then set aside over night, filtered, ignited and weighed as $BaSO_4$.

"*Total Sulphur.*—One gramme of material is weighed out in a large platinum crucible and fused with Na_2CO_3 and a little KNO_3, being careful to avoid contamination from sulphur in the gases from the source of heat. The melt is treated in the crucible with boiling water and the liquid poured into a tall, narrow beaker and more hot water added until the mass is all dissolved. The solution is then filtered. The filtrate contained in a No. 4 beaker is to be acidulated with HCl and made up to about 250 cc. with distilled water, boiled, the sulphur precipitated as $BaSO_4$ and allowed to stand over night.

* **Evaporation to dryness is unnecessary.**

"*Loss on Ignition.*—Half a grain of the cement is to be weighed out in a platinum crucible, and blasted 15 minutes. The loss by weight, which is checked by a second blasting of 5 minutes, is the loss on ignition."

ART. 64. TESTS FOR HOMOGENEITY.

In Europe various tests have been proposed for the purpose of detecting the adulteration of Portland cement. These tests are not usually of a nature intended for use in specifications for the reception of material, but may sometimes be of use in studying the characteristics of various brands of cement or in classifying a product of doubtful character. The materials sometimes met with as adulterations include powdered limestone or shale, blast-furnace slag, hydraulic lime, trass, etc. The nature of the tests depends upon that of the adulteration to be discovered.

The specific-gravity test is sometimes utilized for this purpose, the foreign matter being lighter than cement. The differences, however, are so small that the test at best is rather an uncertain one.

The determination of the loss upon ignition may show the presence of foreign matter containing volatile elements, while chemical analysis, separating the fine and coarse parts of the cement and comparing the results, is sometimes resorted to, as stated in Art. 63.

Microscopic Test.—The use of the microscope for the purpose of determining the character of the substances present in cement has often been proposed. Prof. Le Chatelier made a careful study of Portland cement by examining sections of underground clinker

by polariscopic analysis. He thus demonstrated the possibilities of this method in the scientific investigation of the nature of the material.

This method is not, however, applicable as a test for homogeneity. Attempts have also been made to determine the character of the cement by studying the grains of which the powder is composed under the microscope. For Portland cement, it has been observed that the active portion of the cement is composed of grains of angular form and metallic lustre, and that the parts of earthy appearance are probably inert. It has also been found that the color of the grains seems to bear some relation to their value in the cement. Further study may reveal more positive indications of value based upon the microscopic appearance, but it seems unlikely that this method will be applied to the determination of value in practice.

For tests of homogeneity, the employment of an ordinary magnifying-glass may perhaps give useful results. M. Feret, who made a study of the matter and presented a report to the French Commission upon Methods of Testing Materials, recommends that the material to be examined be sifted through the sieve of 4900 meshes per square centimeter and the portion retained by that sieve be used in the examination, on account of the difficulty of observing the grains when mixed with the impalpable powder. It is also suggested that two glasses be used: the first of a powder of about three diameters to examine the general appearance and uniformity of the material; the second of about eight diameters to study in detail the various grains. The material is placed upon a black surface to be examined. The

points to be noticed are the form, color, and transparence of the grain and the appearance of its fracture. It is also desirable to test the hardness with a steel point and the solubility in a drop of water or acid. It is to be borne in mind that the character of the material in the coarse particles is not necessarily the same as in the finer portions, or at least the proportions of the various ingredients may not be the same.

M. Feret found that pure cement, thoroughly well burned, gave "grains all of the same appearance, black, opaque, angular, hard, and with a rough fracture. Mixed with a drop of water they show at first no change but after several minutes a sort of halo appears, produced by the beginning of crystallization of the soluble compounds. These grains color immediately in hydrochloric acid to a yellow, but are completely dissolved with difficulty.

"Rock less burned gives grains equally opaque, but of color less deep, varying to brown, gray, or green. The underburned rock gives gray or yellow grains, which crush easily under the point of a knife, and are attacked by acids with the disengagement of carbonic acid."

"When instead of material prepared in the laboratory and thoroughly homogeneous, the residue obtained from market grades of cement is used, the appearance is very different even if the material be of best quality. The color is less deep and the material appears very heterogeneous. Such cements contain always, with many of these black, brown, or green grains, a large number of more vitreous material, green, yellow, and white, without containing foreign matter."

"When the cement is less well burned the color of the large grains becomes more clear, and the glass shows an increasing number of gray friable grains, the black grains decreasing in numbers."

"It is not uncommon to find in the cement clinker pieces of bright colors, blue, green, violet, red, and white; these materials are usually soft and porous."

"Carbon in black and brilliant grains, with conchoidal fracture, is found in all the specimens, and easily known."

"The débris of flint from the millstones is not easily distinguished from certain underburned cement grains; they are the gray morsels, hard and opaque. They differ from the cement grains in not being attacked by water or acids."

"The appearance of grains of slag vary according to the nature of the slag. Commonly, the grains are compact, of a bluish-gray color, and smooth, clean fracture. Sometimes the grains are vitreous and black. The granular slags employed in making slag cements are soft, and leave few grains. Their débris has the appearance of colorless glass, or tint of yellow or green, and fractures easily under the point of a knife."

"Grappiers give round grains, usually more clear in color than the grains of cement."

"Gypsum added to cement clinker before grinding may show large white crystalline grains easily seen. They may be identified by their hardness and solubility. Plaster is difficult to recognize, because it grinds fine and leaves no crystals."

When plaster has been added to cement, it may sometimes be detected by separate analyses of the fine and

coarse parts, as to sulphuric acid. The fine parts containing the plaster give the higher results.

Le Chatelier's Test.—This method of detecting adulteration, proposed by Prof. Le Chatelier, consists in forming a liqiud, by the mixture of methylene iodide and benzine, of density slightly below that of cement and above that of slag, and separating by its means the cement from the adulteration. It is thus described by Prof. Le Chatelier:

"The first operation is the preparation of a liquid of proper density for the separation,—2.95 for example. In this liquid the cement sinks to the bottom and the slag floats on the surface. To prepare the liquid add to the methylene iodide of density 3.1 a small quantity of benzine, stopping the moment a crystal of aragonite of density 2.94 just remains at the surface. It is well not to make the mixture directly, but to make two mixtures—the one a little lighter, the other a little heavier, than the density sought; thus obtaining a more progressive variation, and more easily regulated."

"The apparatus consists of a glass tube (Fig. 30) 10 millimeters in diameter, 70 millimeters high, widened into a funnel at top and terminated at bottom in a point, with an orifice, 1 millimeter in diameter. This orifice is closed on the interior a little above the bottom, by a small emery stopper, fastened to a long glass rod, which issues from the top of the tube.

"To make an experiment, the stopper is wet with water (grease is dissolved by the liquid), to prevent leakage. Two grammes of cement are introduced, then five cubic centimeters of liquid (density 2.95). It is then agitated in a lively manner with a small platinum

thread bent around into a hook, in order to drive out the bubbles of air and thoroughly mix the cement in suspension in the liquid. Finally, it is allowed to settle for an hour; after that time there is formed two layers—the cement at the bottom and the slag at the top. The

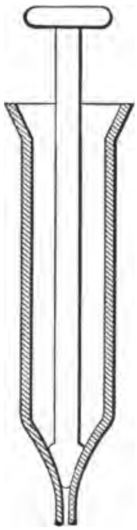

FIG. 30.

stopper of emery is lightly raised by the rod to which it is attached, letting out the cement and part of the liquid, and is then replaced. The cement is caught upon a filter, through which the liquid passes into a flask, when it is ready for another operation.

"The slag and remainder of the liquid are received upon another filter. Finally the tube and filters are washed with benzine and dried; the cement and slag are weighed, and analyzed chemically if thought proper."

The cost is said to be the principal objection to this method, although but a small quantity, a part of a cubic centimeter of iodide of methylene, is required for each operation.

ART. 65. ABRASIVE TESTS.

Cement to be used for sidewalks, floors, or artificial stone is sometimes submitted to tests for resistance to abrasion. This test is frequently employed in Germany, the apparatus designed by Prof. Bauschinger being used. This apparatus consists of a cast-iron disk 122 centimeters in diameter and 3 centimeters thick, mounted to rotate horizontally at about 20 revolutions per minute. Specimens 6×6, 10×10, or 12×12 centimeters in section are employed. They are held upon the disk with a pressure of 30 kilogrammes, and 20 grammes of standard sand are added for each 10 turns. 200 turns are given, and the loss in weight of the specimen is determined.

Fig. 31 shows a similar apparatus made by the Riehle Bros. Testing-machine Co., and used for brick and stone tests. Abrasion tests, when employed, are usually made for both neat cement and sand mortar. The test of mortar as used in practice is evidently the more important. Resistance to abrasion varies with the character of sand used, and for sand mortar depends upon the adhesion of the cement to the sand and the hardness of the grains of sand. Sand mortars with moderate proportions of sand give better resistance to abrasion than neat cement.

FIG. 31.

at the volume of solid
ry in air and saturated
volume of paraffine dis-
n water, and the total
directly the volume of
pose an apparatus is
to the Schuman volu-
removable cover to the

ERMEABILITY.

is quite distinct from
is is not necessarily the
meability, like those for
ortant in the studies of
re not suitable for use
tion of material. The
made by forcing water
er pressure. This may
ting the mortar directly
te head of water, or by
o a small pressure from
e the air is exhausted,
ow. The latter method
Europe, although the
n France.
32 has been frequently
sists of a heavy cylin-
upper edge, upon which
linder (*d*). The speci-
square centimeters and

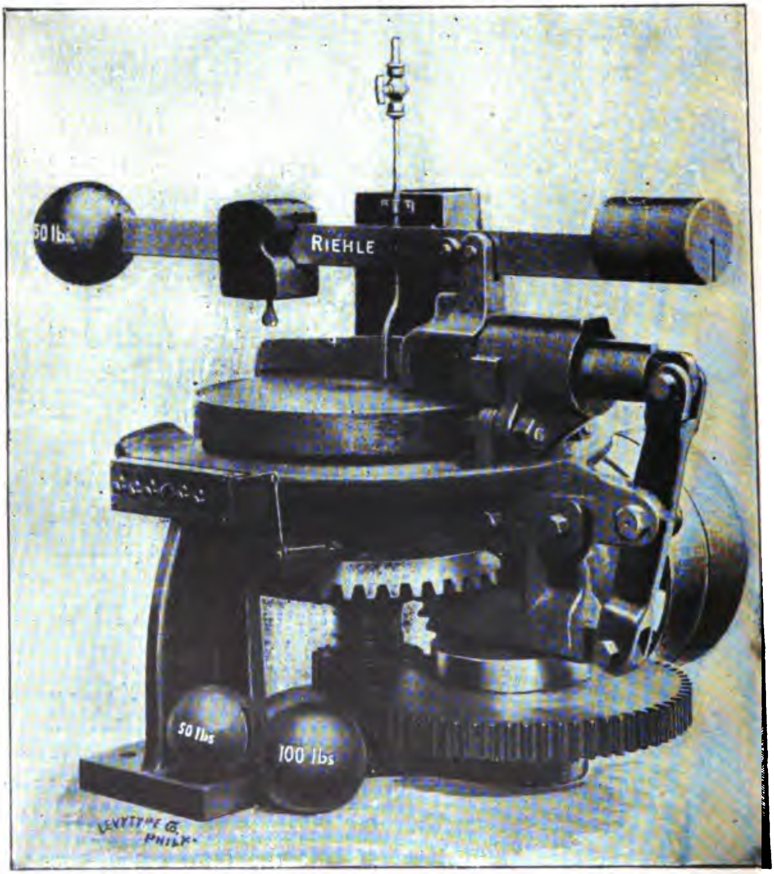

FIG. 31.

Art. 66. Tests for Porosity.

Tests for the porosity of mortar are interesting in studying the properties of the materials and methods of gauging them. The porosity may often be a matter of importance as affecting the durability of mortar subjected to the action of disintegrating agencies. These tests are not employed for the reception of material. The porosity depends to a much greater extent upon the quantity of water used in gauging, and the degree of compression used in forming the briquette, than upon the character of the cement or sand employed, although probably the fineness of these materials has some influence.

The test for porosity consists in determining the ratio of the volume of voids to the total volume of the mortar. The difficulty of determining when the voids are completely filled with liquid, or when the mortar is quite dry, makes the process a somewhat uncertain one, and requires that a definite procedure be followed in order to arrive at concordant and comparable results.

The method usually followed is to measure the total apparent volume and the volume of material: the volume of voids is then the difference of the two; this divided by total volume is the percentage of porosity. To measure the total apparent volume, the simplest method is to make the block of such form that it may be directly measured. When this method is not employed the total volume may be obtained by weighing the block in a saturated condition in water and in the air; the difference between the two weights is the weight of water displaced,

from which the volume may be found. In order to obtain the same state of saturation the weight in water should be taken immediately before that in air. Grease is also sometimes applied to the surface of the block to prevent change during the weighing.

To obtain the volume of solid material in the block, the difference between the weight of the block when dry, in air, and of the saturated block in water is obtained. This difference is the weight of water displaced by solid material. To secure good results the entire dryness in the first instance and the complete saturation in the second is essential. The block may be placed in warm dry air for a period sufficient to permit the weight to become constant. For this purpose it is necessary that the temperature be the same in all cases, as the amount of hygrometric water given off depends upon the temperature of drying; 100° to 110° Fahr. has been sometimes employed, and is recommended by the French Commission on Standard Tests. After the dry weight is obtained, considerable difficulty may be experienced in getting complete saturation. If the block be simply immersed, air will be retained in the voids, and a long period required to obtain a constant weight. Boiling is sometimes resorted to, but has the disadvantage of perhaps causing change of volume in the mortar. The best method of expediting the test is to exhaust the air by placing the specimen in water under the receiver of an air-pump.

Prof. Tetmajer recommends * that a temperature of

* Methoden und Resultate der Prüfung der Hydraulischen Bindemittel (Zurich, 1893).

110° C. be used in drying, and that the volume of solid matter be obtained by weighing dry in air and saturated in paraffine, and determining the volume of paraffine displaced. The block is then put in water, and the total volume obtained by measuring directly the volume of water displaced. For this purpose an apparatus is employed which is very similar to the Schuman volumenometer, Fig. 5, but with a removable cover to the dish to admit the specimen.

Art. 67. Tests for Permeability.

The permeability of mortar is quite distinct from its porosity, and the more porous is not necessarily the more permeable. Tests for permeability, like those for porosity, are interesting and important in the studies of the properties of mortar, but are not suitable for use in specifications for the reception of material. The common test for permeability is made by forcing water through a cake of mortar under pressure. This may be accomplished either by subjecting the mortar directly to the pressure of a considerable head of water, or by subjecting the block of mortar to a small pressure from a column of water above, while the air is exhausted, forming a partial vacuum below. The latter method has been usually preferred in Europe, although the former has been made standard in France.

The apparatus shown in Fig. 32 has been frequently employed in these tests. It consists of a heavy cylindrical glass jar (*a*) with a ground upper edge, upon which is accurately fitted the second cylinder (*d*). The specimen (*c*), having a section of 20 square centimeters and

a thickness of 1 centimeter, is fastened and made water-tight in the cylinder (*b*) by means of a rubber packing-

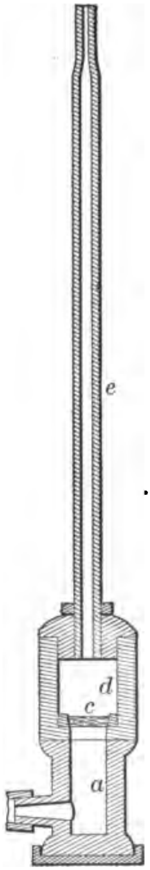

FIG. 32.

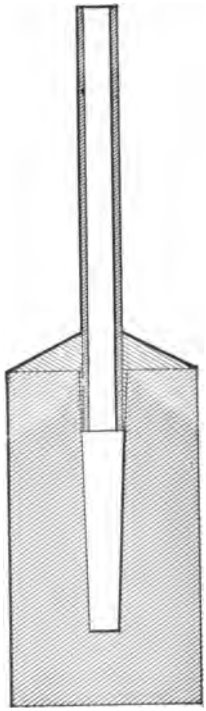

FIG. 33.

ring. A ground-glass stopper covers the cylinder (*b*) and carries the graduated tub (*e*), which has a capacity of 200 cubic centimeters and is graduated to 1/2 centi-

meter. The space under the specimen is connected with an air-pump and a mercury manometer, a stop-cock being placed in the tube connecting with the air-pump. In using the apparatus, after the specimen has been placed in the cylinder and the cover clamped down, the air is exhausted from *a*, the stop-cock closed, and the graduated tube filled with water to the zero mark. The quantity of water percolating through the specimen may then be read from the scale for any desired unit of time.

The arrangement shown in Fig. 33 is also used to some extent in Europe. It consists of a hollow cylin-

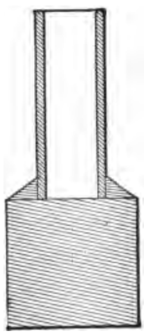

FIG. 34.

drical block, 110 millimeters in diameter and 200 millimeters high, of the mortar to be tested, into the top of which a glass tube is set with neat cement. In making the test a rubber tube is connected with the glass tube and with a vessel placed at such an elevation as will give the pressure desired, which varies according to the mortar to be tested.

A cubical block, arranged as shown in Fig. 34, is also frequently employed. For this purpose the stand-

ard block as used for compressive tests may be employed. This form is recommended by the French Commission upon Methods of Testing Materials, as follows:

"The permeability of cements and mortars may be expressed by the number of liters of water which transverse a cube with faces of 50 square centimeters during a given time.

"The water is supplied by a glass tube 35 millimeters in diameter and 110 millimeters high, sealed vertically by the aid of neat cement upon the upper face of the block. The upper end of the tube is connected by a rubber tube with a reservoir raised to an elevation corresponding to the head desired. The heads adopted, according to the permeability of the mortar, are 0.10 meter, 1 meter, and 10 meters.

"Before the test is made, the blocks should be immersed for 48 hours, with such precautions as are necessary to secure as complete saturation as possible. After beginning the experiment the block is kept completely immersed.

"The rate of filtration is determined after 24 hours, 7 days, 28 days, 3 months.

"The determinations are made for three blocks, the mean results being taken for the two blocks most concordant.

"The *standard test* for permeability is to be made upon standard plastic mortar 28 days old, kept under water.

"For tests upon mortars of different ages and compositions, it is recommended to employ 1 to 2 and 1 to 5 mortars made plastic, and 7 days, 28 days, and 3 months old."

The permeability of mortars to gases is a matter

upon which experiments are very desirable, but concerning which comparatively little is known.

ART. 68. FROST TESTS.

Tests are frequently made upon cement mortars to determine the effect of freezing before setting or while the mortar is still comparatively fresh, for the purpose of investigating the safety of using the mortar in freezing weather, or the best method of so using it.

These tests are usually made by exposing briquettes to freezing temperatures, either by taking advantage of natural low temperatures, or by using a freezing mixture and comparing the results of tensile tests upon briquettes so treated with those kept under normal conditions.

Tests of this kind may be of much value in showing the relative properties of various materials, and often give very interesting results. They are to be used with caution, however, in determining from them the probable effect of freezing upon work in which the mortar may be used. Frequently the results of briquette tests, and the action of the material in large masses in construction are not concordant. Injury to work may perhaps result not only from the injurious effect of frost upon the strength of the material, but also from expansive action upon the mass of mortar, after setting, while still too weak to offer effectual resistance to distortion.

ART. 69. TEST FOR YIELD OF MORTAR.

In some laboratories it is the custom to make tests of the yield of mortar obtained from given weights of the materials employed. This may sometimes be of importance as affecting the economy of use of various materials, while a study of the differences obtained with different material is interesting.

In conducting such tests it is evidently necessary to adopt a standard method of gauging the ingredients, the volume of the resulting product being much affected by variations in manipulations. The method employed is usually to measure directly the volume of paste obtained by mixing to standard consistency a unit weight of neat cement or of cement and sand in proper proportions. For this purpose the paste is put in a graduated glass cylinder, care being taken to eliminate all of the air-bubbles.

Sometimes the test is made by making blocks of the paste, which are allowed to set, their volumes being subsequently obtained by greasing their surfaces and taking the difference of weight in air and water.

ART. 70. TESTS OF SAND.

Tests of the sand to be used in mortar are of much value in determining the relative value of different sands as well as in studying the effect of variations in the nature, form, or size of grains of which it may be composed.

Complete tests should include an examination of the nature of the sand, its fineness as shown by the amount

retained by various sieves; the form of grain which may be examined under a glass; its specific gravity or the weight of a unit volume; its mineralogical character. Tests of the tensile strength of mortar made from the sand to be tested as compared with similar tests made upon standard sand are of most importance as indicating the value of the sand to combine with cement in forming mortar.

CHAPTER IX.

CEMENT MORTAR AND CONCRETE.

ART. 71. SAND FOR MORTAR.

As hydraulic cement is commonly mixed with certain proportions of sand, when used in construction, the nature and quantity of sand used, and the method of manipulating the materials in forming the mortar, have nearly as important an effect upon the final strength of the work as the quality of cement itself.

In testing cement, a standard sand is usually employed. This sand may be obtained quite uniform in quality. In the execution of work, however, local sand must generally be employed; this varies widely in character, and should always be carefully considered upon any important work, where the development of strength and lasting qualities in the mortar are of importance.

The importance of the quality of sand in mortar is not commonly appreciated, and but little attention is usually given to securing good sand even when the cement is subjected to rigid requirements.

Mr. Newman, in his book on concrete, in speaking of the materials used in concrete, says: "Considering the very varied character of sand and gravel, it seems that more attention should be given to the particulariza-

tion of the sand and gravel, remembering the locality of the work in each case, and the geological features of the district from which, for reasons of economy, the sand or gravel must be obtained.

"The value of it from an engineering point of view may be very different, even in a small area; and to be most particular as to the character and quality of Portland cement, and apparently regardless of that of the sand and gravel, although the latter form 85% to 93% of the volume of concrete at the time of mixing, is hardly capable of vindication, especially as Portland-cement concrete should be a monolithic mass, and the effect of sand is to retard induration and decrease strength."

The *chemical nature* of the sand does not appear to have any important bearing upon its usefulness in mortar. Silicious sand is sometimes thought to exercise a slow puzzolanic action, and perhaps aid somewhat in the final hardening of the mortar. It is usually the best sand for the purpose. Calcareous sands are good, if not friable or composed of soft particles. Argillaceous sand is usually less desirable, and has been found in some instances apparently to cause ultimate disintegration in sea-water,* although a small admixture of clay in the sand may not be objectionable, and has been shown in some instances not to decrease the strength when present to an extent not exceeding 10% of the sand.

A sand for use in mortar should be clean, and as free from loam, mud, or organic matter as possible. In general, the presence of any foreign matter is to be avoided.

* Annales des Ponts et Chaussées, 1890, vol. II. p. 277.

The sand should also be as sharp as possible; if it be composed of angular grains, it will compact much closer and make a stronger mortar when used with the same proportion of cement than if it be composed of rounded grains.

Coarse sand is usually preferable to that which is very fine, provided it be fine enough to give a smooth mortar, as it gives better strength. The coarse sand presents less surface to be coated with cement, and the interstices are more easily filled. Fine sand requires more water in mixing in order to arrive at the same consistency, and thus gives usually a more porous mortar. Fine sand may, however, be desirable when an impervious mortar is the object.

The use of a mixture of grains of various sizes is usually desirable, as giving less voids to be filled by the cement; and it is frequently found that when the cement is not in considerable excess the strength obtained by such a mixture is much greater than is given by either the large or small grains alone.

This is doubtless due to the voids in the sand being more completely filled by the cement. Large grains of uniform size seem desirable where a meagre mortar is to be employed, the quantity of cement being insufficient to fill the voids and only used to coat the grains and cement them together.

Fine sand is objectionable in mortar exposed to the action of sea-water on account of the increased porosity.

In using quick-setting cement the dryness of the sand is a matter of importance; if the sand be damp when the mixture of sand and cement is made, sufficient moisture may be given off to induce hydration

previous to the addition of the water. With slow cements this is of less consequence.

M. Candlot found * cement left in contact with sand which was slightly damp, not sufficiently so to cause the cement to set, was greatly modified in action, probably through the hydration of the aluminate of lime.

Cement left ten minutes in contact with sand containing 3% of moisture, and then sifted out, had its time of setting increased from a few minutes to several hours. When the sand was very wet, the action was more serious and a loss of strength resulted.

ART. 72. PROPORTIONING MORTAR.

The relative proportions of the ingredients to be used in mortar are usually stated as a ratio of parts of cement to sand, and the quantities are determined either by weight or volume. Cement should always be measured by weight on account of the variation in volume caused in packing, and the difficulty of measuring by volume always in the same way, while the sand may conveniently be measured by volume.

The proportions of sand and cement to be used in any instance depend upon the nature of the work and the necessity for the development of strength or imperviousness in the mortar. The volume of interstices to be filled varies with the forms and sizes of the grains of sand, and the quantity of cement necessary to reach the same strength with different sands varies considerably. The volume of a given weight of sand is also greater when

* Ciment et Chaux hydrauliques (Paris, 1891).

damp than when dry, and the same proportion to a given volume of sand gives a richer mortar when the sand is measured in a damp condition than when measured dry.

The proportions most commonly used in ordinary work are, for natural cements, one part cement to one or sometimes two parts sand, and for Portland cement one part cement to three parts sand. If the proportions for the mixture were regulated by the value of the sand the interests of economy might frequently require changes in proportions, and would usually demand the use of the best sand obtainable.

Good sand in a 1 to 3 mixture frequently gives greater strength than a poorer one mixed 1 to 2, and either mortar may give equally good results in practice.

The cement in mortar must, for the best results, both coat the grains of sand so as to cause them to adhere to each other, and fill the voids between them. Mortar to be exposed to the action of water, particularly sea-water, should always contain a surplus of cement over what is necessary to fill the voids in the sand.

M. Candlot gives as a minimum for mortar to be used in sea-water a proportion of 600 kilogrammes of cement to a cubic meter of sand, which is to be increased when the cement is not finely ground.

Fine sand is to be avoided, if possible; when used, the proportion of cement to be increased.

The complete filling of the voids in the sand so as to exclude the water from the interior of the mass and prevent the action of the magnesian salts upon the cement is in such work a matter of first importance.

When the mortar is to be subjected to the action of

fresh water its permeability may not be a matter of so great consequence, and in many instances less rich mortar may frequently be used to advantage, provided sufficient strength be obtained for the given purpose. The carbonizing of the lime forms a protection to the mass of mortar, which is not subject, as in sea-water, to the action of the magnesian salts.

ART. 73. GAUGING MORTAR.

In mixing cement mortar, the cement and sand are first thoroughly mixed dry, the water then added, and the whole worked to a uniformly plastic condition. The value of the mortar will depend upon the thoroughness of the operation; the cement must be uniformly distributed through the sand during the dry mixing, while thoroughly working the mass after the addition of the water will greatly increase its strength. In mixing by hand, by the ordinary method, a platform or box is used; the sand and cement are placed upon the platform in layers, with a layer of sand at bottom, and then turned and mixed with shovels until properly distributed through the mass. The material is then formed into a ring, or a mound with a crater at the center, and all the water necessary added at once, after which the material is thrown up from the sides until the water is all taken up, and then worked into a plastic condition.

In order to secure proper manipulation of the materials on the part of the workmen, it is quite common to require that the whole mass shall be turned over a certain number of times with the shovel, both dry and wet.

The mixing should be quickly and energetically done,

only such quantity being mixed at once as can be used before the initial set of the mortar takes place.

The cement should not be left in contact with the sand for any considerable time before being used, or a considerable quantity should not be mixed dry and left to stand until wanted, as the moisture commonly in the sand will to some extent act upon the cement.

Upon large works mechanical mixers are frequently employed, with the advantage of greatly lessening the labor of manipulating the material, and also of insuring thorough mixing.

The quantity of water to be used in gauging mortar can be determined only by experiment in each instance. It depends upon the nature of the cement and sand, and upon the proportion of sad to cement. The water may be considered as made up of two parts—that necessary to gauge the neat cement to a paste, and that required to wet the surfaces of the sand. The first varies directly with the quantity of cement, the second with that of the sand. Fine sand requires more water than coarse sand to reach the same consistency, and mortar of fine sand should be made a little more wet than when of course sand, to give the best results in practice. The quantity of water also varies with the dryness of the sand and its porosity.

The amount of water to be used in mixing mortar for ordinary masonry is such that the mortar when properly mixed shall have a stiff plastic condition. It should not be a soft, semi-fluid mass. The proper consistency is described by M. Chandlot as such that if a ball of mortar be formed in the hand and allowed to fall through a small height, it should neither lose its

form nor crack; the ball should not be wet enough to stick to the hand. The best results are usually obtained by mixing with as little water as will admit of proper manipulation in the work, and wetting the surfaces with which it is to be in contact.

In all cases the proper quantity of water should first be determined by experiment, and afterward, in preparing the mortar for use in work, the required quantity should each time be added by measurement. The addition of water little by little, or from a hose, should never be allowed.

Art. 74. Preparation of Concrete.

Concrete is any mixture of mortar with coarse material, usually gravel or broken stone, the office of the mortar being to bind together the pieces of the aggregate and fill the spaces between them. In engineering work the mortar for concrete is commonly formed from hydraulic cement, the term *beton* being also frequently used to designate hydraulic concrete.

In preparing concrete by hand the mortar is mixed in the usual manner; then the stone is spread over the top of the layer of mortar and thoroughly mixed with it by turning with shovels. The stone should be sprinkled before being mixed with the mortar, sufficiently to wet its surfaces and prevent the absorption of the water from the mortar, thus promoting the adherence of the mortar to the aggregate.

Mortar for concrete should never, as is frequently done, be reduced to a fluid state; not only is the resulting strength of the mortar reduced by so doing, but it cannot be properly mixed with the aggregate to form

a homogeneous mass, as the cement washes out of the mixture. The mortar should, however, be sufficiently soft to mix readily with the aggregate to a cohesive mass, which may be placed and compacted without difficulty in the work. The consistency of concrete must in each instance depend upon its nature and method of use; the greatest strength may usually be attained by mixing somewhat dry and heavily ramming, the mortar being of such consistency that the concrete becomes somewhat jelly-like, water being brought to the surface in ramming. An extreme either of dryness or wetness may be injurious.

Mechanical mixers are frequently employed for preparing concrete, and are very useful in saving labor where considerable quantities are used. There are a number of forms which have proven effective in use, but it seems unnecessary to enter into a discussion of them here.

The aggregate used for concrete should be as hard and durable as possible, and that of angular form is preferable to rounded. Angular forms give a greater surface for the adherence of the mortar in proportion to volume while leaving a less volume of interstices to be filled with mortar. The materials should be uniform in quality. Where gravel is used which varies in quality, it should be blended by mixing in order to obtain uniform strength in the concrete. Porous aggregates are to be avoided, as they are likely to absorb the cement. When the materials are absorbent, they should be saturated in sprinkling before using, in order to avoid withdrawing water from the mortar before setting takes place.

The quantity of sand used in concrete should be such as is necessary to fill the voids in the aggregate, while the quantity of cement depends upon the strength necessary in the work under consideration. When the concrete is required to be water-tight, the amount of cement paste must be sufficient to fill the interstices in the mixture of stone and sand. The quantity of sand necessary to fill the interstices in the stone may be determined by filling a measure with stone as closely as possible, and then measuring the quantity of water which can be poured into the measure; this gives the volume of sand required. If the proper quantity of damp sand be added to the stone in the measure by shaking it down so as to fill the voids, the volume of water which can then be put in the measure is the volume of cement paste necessary to fill the voids in the aggregate.

The strength of concrete usually varies nearly in proportion to the amount of cement used in forming it. When a strong concrete is desired, it should be obtained by increasing the richness of the mortar in cement, not by increasing the proportion of mortar to large material above the point at which the sand fills the interstices in that material. If the proportion of sand be less than this, the resulting concrete will be porous and not thoroughly solidified; if it be greater, the excess of sand may be an element of weakness in the concrete.

In the use of concrete in considerable masses the main body of the work is sometimes formed of very weak concrete, with a facing of stronger water-tight concrete to protect it. This weak concrete is frequently formed by omitting the sand altogether and simply coating the stone lightly with neat cement, causing the

stones to adhere to each other, thus forming a mass sufficiently firm for foundations in many locations when protected by a covering of richer concrete. The voids in a mass of ordinary broken stone vary from about 4/10 to 5/10 of the volume, depending upon its uniformity in size. Where there is considerable variation in size, the voids may be somewhat less. When the interstices are to be filled, it is desirable that the aggregate contain material of various sizes, to reduce the volume of interstices. For this reason small gravel is sometimes mixed with broken stone in the preparation of concrete.

The proportions in common use for concrete of Portland cement vary from 1 part cement, 2 parts sand, and 5 parts broken stone to 1 part cement, 4 parts sand, and 8 or 10 parts broken stone or gravel. Usually the mortar is made richer when natural cement is used. The proportions of course vary with the character of the materials to be used as well as that of the work to be done, and can only be properly determined by the exercise of good judgment, in the light of experience.

ART. 75. YIELD OF MORTAR AND CONCRETE.

The volume of mortar formed by mixing given quantities of cement and sand depends upon the densities of the materials and the volume of interstices in the sand. It is affected also by the method of preparing the mortar, the uniformity of the mixing, and the degree of compactness given.

The net volume of materials entering into the composition of mortar or concrete is readily found from their weights and densities, but it represents only approximately

the resulting volume. An accurate knowledge of the yield of any particular mixture is to be obtained only by experiment upon the materials to be employed.

Portland cement is usually sold in barrels containing about 375 lbs. Natural cements are lighter, and are put up in barrels of 260 to 320 lbs. Barrels of Rosendale cements usually contain 300 lbs.

The amount of neat cement paste made by a given weight of cement powder varies with the specific gravity of the cement and the amount of water necessary in gauging. The lighter cements require more water and yield less paste for a given volume of cement than the heavier ones. To form a cubic foot of plastic paste requires usually from 75 to 90 lbs. of natural-cement powder; about 80 to 85 lbs. of Rosendale cement being required, while about 95 to 100 lbs. of Portland cement are necessary.

In mixing sand mortar, where the cement and sand are proportioned by volume measured loose, the quantities required to form a cubic yard of mortar are approximately as follows:

	Natural Cement. Pounds.	Portland Cement. Pounds.	Sand. Cu. Yd.
1 to 1 mortar ...	1050 to 1250	1350 to 1530	.65 to .70
1 " 2 "	640 " 720	810 " 920	.80 " .85
1 " 3 "	500 " 575	620 " 690	.93 " .96
1 " 4 "	400 " 460	500 " 575	1.00
1 " 5 "	320 " 375	400 " 460	1.00

For concrete, when the aggregate is broken stone of uniform size, it is necessary, in order to fill the interstices with mortar, that the volume of morter be 50% to 60% that of the aggregate. For such concrete a mixture of about .9 cubic yard of broken stone with .50

to .55 cubic yard of the mortar as given above yields about one cubic yard of concrete. This gives the proportions sometimes employed for strong concrete: 1 part cement, 2 parts sand, and 4 parts broken stone; or 1 part cement, 3 parts sand, and 5 parts broken stone.

Where the stone is more irregular in size, or if gravel of smaller size be added, a smaller proportion of mortar may give good results. Thus, .9 cubic yard of broken stone with .4 cubic yard of gravel and .3 cubic yard of mortar has been found to yield 1 cubic yard of good concrete. This, using 1 to 2 mortar, gives the proportion 1 part cement, 2 parts sand, 3 parts gravel, and 7 parts broken stone.

When the amount of mortar used is less than that indicated above, and the interstices in the aggregate are not filled, the yield of concrete is about equal to the volume of aggregate employed.

Art. 76. Mixtures of Lime and Cement.

Slaked lime is sometimes mixed with hydraulic cement for the purpose of decreasing the cost of construction. Experiments seem to indicate that a very considerable percentage of lime may frequently be added without material loss of strength in the mortar.

With Portland cement the addition of lime weakens the mortar somewhat, the decrease in strength augmenting rapidly as the proportion of lime increases.

With some American natural cements it has been found that a certain amount (sometimes 30% to 40%) of lime may be added without sensibly decreasing the strength of the mortar or impairing its hydraulic prop-

erties. This may be due to puzzolanic action on the part of the cement, which is of high hydraulic index.

When mortar is not to be used under water, and only moderate strength is necessary, it may often be economical to form the mortar by the admixture of lime, better results being obtained than by using a higher proportion of sand. The mortar thus formed is less porous than that made with a larger proportion of sand, and it is also more plastic and easier to work. In making the mixture the lime is ordinarily slaked in the usual manner and used in the form of paste, although it may be slaked to powder and mixed dry with the cement. By the first method the thorough slaking of the lime is insured.

The admixture of lime causes the cement to become slower-setting, the quick-setting cement being affected more strongly than the less active ones.

In France a small proportion of Portland cement is sometimes added to hydraulic lime for the purpose of accelerating the setting and increasing the strength of the lime.

Mixtures of natural and Portland cement have frequently been used in the United States for the purpose of modifying the action of the quick-setting material or of cheapening construction. They seem generally to give results compounded of those which would be obtained by using them singly.

The results of all these mixtures will be found to vary with the particular cement employed, and the effect can only be known by trial in each instance. In all cases, to get good results, the mixtures must be very intimate.

Art. 77. The Freezing of Mortar.

Mortar of good Portland, or of many kinds of natural cement, is not injured by freezing, when frozen before it is set. The cement sets with extreme slowness, if at all while frozen, but after thawing it sets and hardens properly. Mortar frozen for short periods—a few days—does not set while frozen, but the experiments of Mr. Cecil B. Smith at McGill University seem to show that if kept frozen for a sufficient period it may finally set while frozen.

The hardening of cement which has been frozen is much more slow than that unfrozen, but it may ultimately gain the same strength.

Masonry constructed during freezing weather is frequently injured by freezing, notwithstanding the fact that the cement itself shows no loss of strength due to freezing. The effect of frost coming upon the work before it is fully hardened is frequently to distort or cause unequal settlement in it, and sometimes repeated freezing and thawing gradually cause the mortar to be thrown out of place or perhaps to become cracked and disintegrated on the outside. The construction of cement masonry during freezing weather is therefore usually more or less hazardous, unless some means be adopted of preventing the freezing action. Many instances may, however, be cited where extreme cold has not injured work constructed, without such precaution, with Portland cement mortar, and it is claimed by many engineers that Portland may be used with impunity in freezing weather, but usually it is not placed in work while a freezing temperature prevails. It is commonly agreed that most

natural cements should not be used when a very low temperature is likely to reach the work in advance of it having attained good strength, and instances are numerous of work having been injured by changing temperature of winter weather, although it may not have frozen for considerable time after setting.

Salt is quite commonly used in cold weather to prevent the freezing of mortar while it is soft. A strong solution, frequently a saturated one, is employed. The salt, by preventing the freezing of the water, prevents any distorting or disrupting action upon the work due to the change in volume of the mortar. The use of salt considerably decreases the activity of the cement, and mortar may stand in a soft condition at freezing temperatures and finally set when the temperature becomes sufficient to induce action.

The loss in early strength of cement mortar which has been mixed with salt water on exposure to low temperature before setting is usually greater than that of mortar without the salt and exposed at the same temperature.

The effect of salt upon the strength of various kinds of cement is quite different. In nearly all, the strength of mortar kept in air is increased by its use. When the mortar is kept under water, most cements have an access of early strength from the use of salt, which is lost later, the final strength being somewhat reduced. This is true of most Portland cements. Some natural cements suffer a material loss of strength when mixed with salt water, while others are entirely ruined by a low temperature with or without the use of salt. Care should always be taken to determine the action of salt

and cold upon the particular cement before using it in this manner.

It is advisable in using salt to protect the mortar from contact with water immediately after setting, as sometimes salt mortar which has been exposed to low temperature may lose its cohesion if submerged soon after setting.

Soda has sometimes been employed to prevent the freezing of mortar, but its use has not become extensive, and has usually proven unsatisfactory.

Hot water should not be used in mixing mortar in freezing weather. It not only decreases the strength of the mortar, but renders it more liable to injury from frost. Heating the stones or bricks in the construction of masonry in freezing weather may be beneficial, as serving to accelerate the setting and keep the mortar from freezing while soft.

The injury done to the mortar by low temperatures is probably not usually due to freezing before setting, but to alternate thawing and freezing while work is still fresh, before hardening is sufficiently advanced to render the mortar capable of adequately resisting the expansive forces. The effect of frost upon mortar which has set is similar to that upon stone or brick, and is due to the increase in volume of water freezing in its pores. Its effect therefore depends both upon the porosity of the mortar and upon the strength it possesses to resist disruption. The more rapid acquisition of strength by Portland cements may give them the advantage they possess in this regard.

Prof. Le Chatelier, from his experiments upon the matter, concludes as follows: "This disintegration, like

that of frozen stone, is more easily accomplished when the mortar offers small mechanical resistance, when the total volume of voids is large, and when the dimensions of each separate void are small. When the voids are sufficiently large, the ice breaks with a pressure less than that which will rupture the mortar. For this reason mortars of large sand are less affected, the voids being larger and less numerous."

ART. 78. POROSITY AND PERMEABILITY OF MORTAR.

The *porosity* of cement mortar depends rather upon the manipulation of the materials in gauging than upon the quality of the cement. When the quantity of cement is insufficient to fill the voids in the sand, spaces are left which permit the absorption of water without increasing the volume of the mortar.

In gauging mortar air-bubbles attach themselves to the wet sand, the number of which is greater as the mortar is mixed more wet. Working the mortar tends to eliminate them. Voids in the mortar are also caused by the evaporation of surplus water used in mixing. Porosity is greater as the quantity of water used in gauging is increased and as the sand used is finer.

The *permeability* of cement mortars varies with the quality of the cement and the circumstances of its use. Mortar of neat Portland cement may be made practically impermeable under a considerable head of water; that composed of cement and sand seems always more or less permeable, but when properly proportioned and mixed eventually permits very little water to pass.

The permeability of mortar decreases rapidly with

its age: for the first few days or weeks after mixing, water passes quite freely through it, but as the hardening process approaches completion its power of resistance is in this particular greatly augmented.

If blocks of mortar be submitted to the continuous filtration of water, the permeability diminishes very rapidly, and after a few months all mortars, except those of very coarse sand and feeble proportion of cement, become practically impermeable.

Both the porosity and permeability are less for mortar rich in cement than for that in which the proportion of cement is small. Mortar mixed dry is penetrated more readily than that mixed to a plastic or semiwet condition. With the lapse of time, however, the mortar mixed dry, if constantly exposed to water, approaches the others in resistance to permeation. The thoroughness of mixing and degree of compacting employed are more important factors than the absolute quantity of water used in mixing.

Fine sand, according to the experiments of M. Alexandre, renders the mortar more porous and less permeable than coarse sand. When the sand is of varying sizes both the porosity and permeability may be low. In any case, to attain a reasonable resistance to penetration, it is necessary that the interstices in the sand be entirely filled with cement. Cleanliness of the sand, its freedom from all foreign material, is of first importance in the preparation of impermeable mortar.

Masonry of ordinary brick or stone can only be made impervious by the application of a coating of some kind to its face. A plastering of neat cement or rich mortar may sometimes be used for this purpose, and

coatings of asphalt or coal-tar have sometimes been successfully employed.

In concrete work where imperviousness is essential, it may be advisable, as with masonry, to coat the face of the concrete. In order that concrete may be reasonably water-tight, it is necessary that the quantity of cement mortar used in preparing it be sufficient to fill the voids in the large material employed, as well as that the voids in the sand be completely filled with cement paste in making the mortar.

Art. 79. Expansion and Contraction of Mortar.

In the use of large masses of masonry or concrete the change that is liable to occur in the volume of mortar may frequently become of importance, and it may be necessary to make provision by which changes in dimension can take place without injury to the work.

The coefficient of expansion for neat cement under the action of heat is, as previously stated, about the same as for iron, although it may vary in individual instances. For mortars containing sand, the coefficient is less than for neat cement.

Cements differ considerably in their behavior during the continuance of the hardening process, as to the change that takes place in the volume of the mortar. Unsound cement is apt to swell and become distorted at the commencement of the process of disintegration, and of course any considerable change of this nature indicates the probable destruction of the mortar. Perfectly sound cement, although not altered in form, is usually changed somewhat in dimensions during hard-

ening: if the mortar be conserved in dry air, a slight shrinkage takes place; if under water, the mortar swells a little.

Prof. Swain, in a series of experiments at the Massachusetts Institute of Technology for a committee of the American Society of Civil Engineers, found that for small blocks of mortar the change was the same in all directions; that for neat cements the linear contraction in air varied from 0.14% to 0.32% for the first twelve weeks after mixing, and the linear expansion in water varied from 0.04% to 0.25%. When sand was used the change was less, giving a contraction in air from 0.08% to 0.17%, and an expansion in water of from 0.00% to 0.08%.

The rapidity of the change varies somewhat with the activity of the cement; the conclusion being that a quick-setting cement changes more in volume than a slow-setting one.

Further experiment is desirable, that the action of the various classes of cement may be better understood.

Art. 80. Effect of Retempering Mortar.

Masons frequently mix mortar in considerable quantities, and, if the mass becomes stiffened before being used by the setting of the cement, add more water and work again to a soft or plastic condition. After the second tempering the cement is much less active than at first, and remains a longer time in a workable condition.

This practice is not usually approved by engineers, and is not permitted in good engineering construction, although there is some dispute as to its injurious effect.

M. Alexandre, from an extensive series of experiments,* concludes that no injury is usually done to mortar by retempering, provided sufficient water be added to make the mortar plastic at the second working. The hardening of mortar so treated is very slow at first, but it may subsequently (the tests extend over three years) gain as much strength as when gauged immediately upon mixing.

It is also frequently claimed that the adhesive properties of mortar are improved by giving it the "second set." The common practice of masons who set fireplace tiling and similar work is based upon this idea. Further experiment to determine this point would be interesting.

The results of experiments other than those already quoted have seemed to show that in some instances injury is done to mortar by retempering, some cements even refusing to set the second time. Until more is known of the action of the material when subjected to this treatment, it seems advisable to mix only such quantity at once as may be used before the initial set of the cement, and to reject any material that may have set before being placed in the work.

* Annales des Ponts et Chaussées, 1888, vol. I. p. 375.

APPENDIX.

SPECIFICATIONS FOR THE RECEPTION OF CEMENT.

GENERAL REMARKS.

IN the discussion which has been given of the various tests applied to cement, the requirements of specifications have been considered, but it is thought desirable to append a few actual specifications to show the requirements employed in practice.

The specifications recommended by the committee of the American Society of Testing Materials for use by American Engineers are first given. These specifications may be considered as the standard of the best American practice at present, although many specifications in common use differ in important particulars from them.

Several modifications of existing practice at the time of their adoption are recommended by these specifications, as in the method of testing soundness and in the use of the Vicat needle for rate of setting.

The British Standard Specifications recommended by the "Engineering Standards Committee" in 1905 are also given in full.

The other specifications given are examples of those in use for the reception of cement upon works.

Some engineers who use considerable quantities of cement of a few brands, or of a single brand, employ no specifications, but depend upon the reliability of the brand, or perhaps upon occasional examinations to show that the material is up to standard. This is frequently the practice upon ordinary railroad work, and in some instances, where the use is continuous and private contracts may be made for the material, is quite satisfactory.

There seems, generally, to be no good reason for stating specifications in an indefinite manner. The conditions to be imposed may as easily be plainly stated, and thus leave no doubt as to the requirements.

A.

AMERICAN SOCIETY FOR TESTING MATERIALS.

REPORT OF COMMITTEE ON STANDARD SPECIFICATIONS FOR CEMENT.

GENERAL OBSERVATIONS.

1. These remarks have been prepared with a view of pointing out the pertinent features of the various requirements and the precautions to be observed in the interpretation of the results of the tests.

2. The committee would suggest that the acceptance or rejection under these specifications be based on tests made by an experienced person having the proper means for making the tests.

3. *Specific gravity.*—Specific gravity is useful in detecting adulteration or underburning. The results of tests of specific gravity are not necessarily conclusive as an indication of the quality of the cement, but when in combination with the results of other tests may afford valuable indications.

4. *Fineness.*—The sieves should be kept thoroughly dry.

5. *Time of setting.*—Great care should be exercised to maintain the test pieces under as uniform conditions as possible. A sudden change or wide range of temperature in the room in which the tests are made, a very dry or humid atmosphere, and other irregularities vitally affect the rate of setting.

6. *Tensile strength.*—Each consumer must fix the minimum requirements for tensile strength to suit his own conditions. They shall, however, be within the limits stated.

7. *Constancy of volume.*—The tests for constancy of volume are divided into two classes, the first normal, the second accelerated. The latter should be regarded as a precautionary test only, and not infallible. So many conditions enter into the making and interpreting of it that it should be used with extreme care.

8. In making the pats the greatest care should be exercised to avoid initial strains due to moulding or to too rapid drying out during the first twenty-four hours. The pats should be preserved under the most uniform conditions possible, and rapid changes of temperature should be avoided.

9. The failure to meet the requirements of the accelerated tests need not be sufficient cause for rejection. The cement may, however, be held for twenty-eight days and

a retest made at the end of that period. Failure to meet the requirements at this time should be considered sufficient cause for rejection, although in the present state of our knowledge it cannot be said that such failure necessarily indicates unsoundness, nor can the cement be considered entirely satisfactory simply because it passes the tests.

STANDARD SPECIFICATIONS FOR CEMENT.

1. *General conditions.*—All cement shall be inspected.

2. Cement may be inspected either at the place of manufacture or on the work.

3. In order to allow ample time for inspecting and testing the cement should be stored in a suitable weather-tight building having the floor properly blocked or raised from the ground.

4. The cement shall be stored in such a manner as to permit easy access for proper inspection and identification of each shipment.

5. Every facility shall be provided by the contractor and a period of at least twelve days allowed for the inspection and necessary tests.

6. Cement shall be delivered in suitable packages with the brand and name of manufacturer plainly marked thereon.

7. A bag of cement shall contain 94 lbs. of cement net. Each barrel of Portland cement shall contain 4 bags, and each barrel of natural cement shall contain 3 bags, of the above net weight.

8. Cement failing to meet the seven-day requirements may be held awaiting the results of the twenty-eight-day tests before rejection.

9. All tests shall be made in accordance with the methods proposed by the Committee on Uniform Tests of Cement of the American Society of Civil Engineers, presented to the society Jan. 21, 1903, and amended Jan. 20, 1904, with all subsequent amendments thereto.

10. The acceptance or rejection shall be based on the following requirements:

NATURAL CEMENT.

11. *Definition.*—This term shall be applied to the finely pulverized product resulting from the calcination of an argillaceous limestone at a temperature only sufficient to drive off the carbonic-acid gas.

12. *Specific Gravity.*—The specific gravity of the cement thoroughly dried at 100° C. shall be not less than 2.8.

13. *Fineness.*—It shall leave by weight a residue of not more than 10 per cent on the No. 100 and 30 per cent on the No. 200 sieve.

14. *Time of Setting.*—It shall develop initial set in not less than ten minutes, and hard set in not less than thirty minutes, nor more than three hours.

15. *Tensile Strength.*—The minimum requirements for tensile strength for briquettes 1 inch square in cross-section shall be within the following limits, and shall show no retrogression in strength within the periods specified.

NEAT CEMENT.

Age.	Strength.
24 hours in moist air.	50–100 lbs.
7 days (1 day in moist air, 6 days in water)	100–200 "
28 " (1 " " " " 27 " " ")	200–300 "

I PART CEMENT, 3 PARTS STANDARD SAND.

Age.	Strength.
7 days (1 day in moist air, 6 days in water).	25– 75 lbs.
28 days (1 " " " " 27 " " ").	75–150 "

16. *Constancy of volume.*—Pats of neat cement about 3 inches in diameter, ½ inch thick at center, tapering to a thin edge, shall be kept in moist air for a period of twenty-four hours.

(*a*) A pat is then kept in air at normal temperature.

(*b*) Another is kept in water maintained as near 70° F. as practicable.

17. These pats are observed at intervals for at least twenty-eight days, and, to satisfactorily pass the tests, should remain firm and hard and show no signs of distortion, checking, cracking, or disintegrating.

PORTLAND CEMENT.

18. *Definition.*—This term is applied to the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials, and to which no addition greater than 3 per cent has been made subsequent to calcination.

19. *Specific gravity.*—The specific gravity of the cement, thoroughly dried at 100° C., shall be not less than 3.10.

20. *Fineness.*—It shall leave by weight a residue of not more than 8 per cent on the No. 100, and not more than 25 per cent on the No. 200 sieve.

21. *Time of setting.*—It shall develop initial set in not less than thirty minutes, but must develop hard set in not less than one hour, nor more than ten hours.

22. *Tensile strength.*—The minimum requirements for tensile strength for briquettes one inch square in section shall be within the following limits, and shall show no retrogression in strength within the periods specified:

NEAT CEMENT.

Age.	Strength.
24 hours in moist air.	150–200 lbs.
7 days (1 day in air, 6 days in water).	450–550 "
28 " (1 " " " 27 " " "	550–650 "

1 PART CEMENT, 3 PARTS SAND.

7 days (1 day in moist air, 6 days in water).	150–200 lbs.
28 " (1 " " " " 27 " " ").	200–300 "

23. *Constancy of volume.*—Pats of neat cement about three inches in diameter, one half inch thick at the centre, and tapering to a thin edge, shall be kept in moist air for a period of twenty-four hours.

(*a*) A pat is then kept in air at normal temperature and observed at intervals for at least 28 days.

(*b*) Another pat is kept in water maintained as near 70° Fahr. as practicable, and observed at intervals for at least 28 days.

(*c*) A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for five hours.

24. These pats to satisfactorily pass the requirements shall remain firm and hard and show no signs of distortion, checking, cracking, or disintegration.

25. *Sulphuric acid and magnesia.*—The cement shall not contain more than 1.75 per cent of anhydrous sulphuric acid (SO_3), nor more than 4 per cent of magnesia (MgO).

B.

SPECIFICATIONS ISSUED BY THE ENGINEERING STANDARDS COMMITTEE.

SUPPORTED BY

THE INSTITUTION OF CIVIL ENGINEERS.
THE INSTITUTION OF MECHANICAL ENGINEERS.
THE INSTITUTION OF NAVAL ARCHITECTS.
THE IRON AND STEEL INSTITUTE.
THE INSTITUTION OF ELECTRICAL ENGINEERS.

BRITISH STANDARD SPECIFICATIONS FOR PORTLAND CEMENT.

Quality and preparation.—(1) The cement is to be prepared by intimately mixing together calcareous and argillaceous materials, burning them at a clinkering temperature and grinding the resulting clinker. No addition of any material is to be made after burning, except when desired by the manufacturer, and if not prohibited in writing by the consumer, in which case calcium sulphate or water may be used. The cement, if watered, shall contain not more than 2 per cent of water, whether that water has been added or has been naturally absorbed from the air. If calcium sulphate is used, not more than 2 per cent calculated as anhydrous calcium sulphate of the weight of the cement shall be added.

Sampling and preparation for testing and analysis.—(2) As soon as the cement has been bulked at the maker's

works, or on the works in connection with which the material is to be used, at the consumer's option, samples for testing are to be taken from each parcel, each sample consisting of cement from at least twelve different positions in the same heap, so distributed as to insure as far as is practicable a fair average sample of the whole parcel, all to be mixed together and the sample for testing to be taken therefrom.

(3) Before gauging the tests, the sample so obtained is to be spread out for a depth of 3 inches for twenty-four hours, in a temperature of 58° to 64° Fahr.

(4) In all cases where consignments are of 100 tons and upwards samples selected as above for each consignment, either at the maker's works or after delivery at the works where the cement is to be used, are to be sent for expert testing and for chemical analysis. In no case is cement so tested and analyzed to be accepted or used unless previously certified in writing by the consumer to be of satisfactory quality. Payment for such tests and analyses to be made by the consumer, the manufacturer supplying the cement required for the same free of charge. When consignments of less than 100 tons have to be supplied, the maker shall, if required, give certificates for each delivery, to the effect that such cement complies with the terms of this standard specification, with regard to quality, tests, and chemical analyses, no payment being made by the consumer for such certificate nor for the making of such tests and analyses.

(5) Should it be deemed more convenient by the consumers that the samples for testing should be taken at the maker's works before delivery, the latter are, in

that event, to afford full facilities to the inspector who may be appointed by the consumers to sample the cement as he may desire at the maker's works, and subsequently to identify each parcel as it may be dispatched, with that sampled by him. No parcel is to be sent away unless a written order has been previously received by the makers from the said consumer to the effect that the material in question has been approved.

Fineness and sieves.—(6) The cement shall be ground to comply with the following degrees of fineness, viz.:

The residue on a sieve $76 \times 76 = 5776$ meshes per square inch is not to exceed 5 per cent.

The residue on a sieve $180 \times 180 = 32{,}400$ meshes per square inch is not to exceed $22\frac{1}{2}$ per cent.

The sieves are to be prepared from standard wire; the size of the wire for the 5776 mesh is to be .0044 inch and for the 32,400 mesh .0018 inch. The wire shall be woven (not twilled), the cloth being carefully mounted on the frames without distortion.

Specific gravity.—(7) The specific gravity of the cement shall not be less than 3.15 when sampled and hermetically sealed at the makers' works, nor less than 3.10 if sampled after delivery to the consumer.

Chemical composition.—(8) The cement is to comply with the following conditions as to its chemical composition. There shall be no excess of lime, that is to say, the proportion of lime shall not be greater than is necessary to saturate the silica and alumina present. The percentage of insoluble residue shall not exceed 1.5 per cent; that of magnesia shall not exceed 3 per cent, and that of sulphuric anhydride shall not exceed 2.5 per cent.

Tensile tests.—(9) The quantity of water used in gauging shall be appropriate to the quality of the cement, and shall be so proportioned that when the cement is gauged it shall form a smooth, easily worked paste that will leave the trowel cleanly in a compact mass. Fresh water is to be used for gauging, the temperature thereof, and of the test-room at the time the said operations are performed, being from 58° to 64° Fahr.

The cement gauged as above is to be filled, without mechanical ramming, into moulds; each mould resting upon an iron plate until the cement has set. When the cement has set sufficiently to enable the mould to be removed without injury to the briquette, such removal is to be effected. The said briquettes shall be kept in a damp atmosphere and placed in fresh water twenty-four hours after gauging and kept there until broken, the water in which the test briquettes are submerged being renewed every seven days and the temperature thereof maintained between 58° and 64° Fahr.

Neat tests.—(10) Briquettes of neat cement are to be gauged for breaking at seven and twenty-eight days, respectively, six briquettes for each period. The average tensile strength of the six briquettes shall be taken as the accepted tensile strength for each period. For breaking, the briquette is to be held in strong metal jaws, the briquettes being slightly greased where gripped by the jaws. The load must then be steadily and uniformly applied, starting from zero, increasing at the rate of 100 lbs. in twelve seconds. The briquettes are to bear on the average not less than the following tensile stresses before breaking:

7 days from gauging	. 400 lbs.	per square inch of section.
28 " " "	.. 500 "	" " " " "

The increase from seven to twenty-eight days shall not be less than:

25% when the 7-day test falls between 400 to 450 lbs. per square inch.

20% when the 7-day test falls between 450 to 500 lbs. per square inch.

15% when the 7-day test falls between 500 to 550 lbs. per square inch.

10% when the 7-day test falls between 550 lbs. per square inch or upwards.

Sand tests.—(11) The cement shall also be tested by means of briquettes prepared from one part of cement to three parts by weight of dry standard sand, the said briquettes being of the shape described for the neat-cement tests; the mode of gauging, filling the moulds, and breaking the briquettes is also to be similar. The proportion of water used shall be such that the mixture is thoroughly wetted, and there shall be no superfluous water when the briquettes are formed. The cement and sand briquettes are to bear the following tensile stresses:

7 days from gauging	.. 120 lbs.	per square inch of section.
28 " " "	.. 225 "	" " " " "

The increase from seven to twenty-eight days shall not be less than 20 per cent.

The standard sand referred to above is to be obtained from Leighton Buzzard. It must be thoroughly washed, dried, and pass through a sieve of 20×20 meshes per square inch, and must be retained on a sieve of 30×30

meshes per square inch, the wires of the sieve being .0164 inch and .0108 inch respectively.

Setting-time.—(12) There shall be three distinct gradations of setting-time, which shall be designated as "quick," "medium," and "slow." *

Quick. The setting-time shall not be less than ten minutes or more than thirty minutes.

Medium. The setting-time shall not be less than half an hour or more than two hours.

Slow. The setting-time shall not be less than two hours or more than five hours.*

The temperature of the air in the test-room at the time of gauging and of the water used is to be between 58° and 64° Fahr.

The cement shall be considered as "set" when a needle having a flat end $\frac{1}{46}$ inch square, weighing in all $2\frac{1}{2}$ lbs., fails to make an impression when its point is applied gently to the surface.

Soundness.—(13) The cement shall be tested by the Le Chatelier method, and is in no case to show a greater expansion than 12 millimeters after twenty-four hours' aeration and 6 millimeters after 7 days' aeration.

Note.—The apparatus for conducting the Le Chatelier test consists of a small split cylinder of spring brass or other suitable metal of 0.5 millimeter (.0197 inch) in thickness, 30 millimeters (1.1875 inches) internal diameter, and 30 millimeters high, forming the mould to which on either side of the split are attached two indicators 165 millimeters (6.5 inches) long from the cylinder, with pointed ends.

---

* When a specially slow-setting cement is required the minimum time of setting shall be specified.

In conducting the test the mould is to be placed upon a small piece of glass and filled with cement gauged in the usual way, care being taken to keep the edges of the moulds gently together while this operation is being performed. The mould is then covered with another glass plate, a small weight is placed on this, and the mould is immediately placed in water at 58° to 64° Fahr. and left there for twenty-four hours.

The distance separating the indicator points is then measured and the mould placed in cold water, which is brought to the boiling-point in 15 to 30 minutes and kept boiling for six hours. After cooling, the distance between the points is again measured; the difference between the two measurements represents the expansion of the cement, which must not exceed the limits laid down in this specification.

(14) The tests and analyses hereinbefore referred to shall in no case relate to a larger quantity of cement than 250 tons sampled at one time.

Acceptance.—(15) No cement is to be approved or accepted unless it fully complies with the foregoing conditions.

C.

U. S. RECLAMATION SERVICE, 1905.

F. H. NEWELL, *Chief Engineer.*

1. *Definition.*—The cement shall be high-grade Portland cement. By the term Portland cement is to be understood the material obtained by finely pulverized clinker produced by burning to semi-fusion an intimate

mixture of finely ground calcareous and argillaceous materials.

2. *Composition.*—It must be of normal composition, in which the proportion of the sum of calcium oxide and alkalies to the sum of the silica, alumina, and ferric oxide must not be less than 1.7 to 1 nor more than 2.2 to 1. It shall not contain over 3 per cent of magnesia nor 2½ per cent of sulphate of lime. But in certain cases where such amounts of these substances are objectionable the engineer in charge may specify lower percentages. Its freedom from uncombined lime shall be determined as in article 12. The question of adulteration may be determined either by chemical analyses or by inspection of the process at the factory.

3. *Bids.*—Bids will be received only from manufacturers or their authorized agents, and the name of the brand offered shall in all cases be stated.

4. *Weight per barrel or sack.*—The average weight per barrel shall not be less than 375 lbs. net. Four sacks shall contain 1 barrel of cement. If the weight as determined by test weighings is found to be below 375 lbs. per barrel, the contractor may be required to supply, free of cost to the United States, an additional amount of cement equal to the shortage.

5. *Barrels; damaged cement.*—If the cement is delivered in barrels, the barrels shall be strong and lined with paper, and the cement shall be free from lumps. Any package that is broken or that contains damaged cement may be rejected by the United States agent in local charge.

6. *Sampling.*—Samples of cement are to be taken from the barrels or sacks with a sampling-tube in such manner as to secure fair average of the packages. They are to

be taken from every tenth barrel or fortieth sack and numbered, and the packages from which they are taken to be sealed and corresponding numbers attached for future identification. The quantities taken are to be kept separate and tested separately. Where the results of tests indicate variation in the quality of the cement, additional barrels or sacks will be sampled and tested.

7. *Aeration and testing.*—No cement shall be shipped until at least sixty days after its manufacture, except that in case of an emergency, and with the approval of the engineer in charge, a shorter time may be allowed, but if the cement shows indications of unsoundness, a longer time may be required. The contractor shall keep in storage, in sacks or barrels, such stocks of cement as the engineer shall require, free of expense to the United States, for sampling and testing during a period of twenty-eight days.

8. *Shipment.*—The engineer shall give notice in writing to the contractor of the approximate requirements for cement shipments and of dates for sampling. In all cases the contractor shall be responsible for the delivery of the cement in good condition at the place of consignment.

9. *Factory inspection.*—The Government engineer, or his authorized agent, shall at all times have liberty to inspect the materials, process of manufacture, and daily laboratory records of analyses and tests at the cement works.

10. *Fineness.*—Ninety-five per cent by weight must pass through a No. 100 sieve having 10,000 meshes per square inch, the wire to be No. 40 Stubbs wire gauge; and 75 per cent by weight must pass through a No. 200

sieve having 40,000 meshes per square inch, the wire to be No. 48 Stubbs wire gauge.

11. *Specific gravity.* — The specific gravity of the cement shall not be less than 3.

12. *Soundness.*—Pats are to be made of neat mortar of normal consistency. The pats are to be moulded on glass plates. They are to be circular in shape, 3 inches in diameter, $\frac{1}{2}$ inch thick in the centre, and drawn to a thin edge at their circumference, and are to be kept under a wet cloth, or in a moist atmosphere, until finally set. One pat is to be put in water, the temperature of which is to be raised to the boiling-point and kept at that point for six hours. If the pat softens, cracks, warps, or disintegrates, the cement is unsound.

13. *Time of setting.*—The cement shall not acquire its initial set in less than forty-five minutes, and must acquire its final set within twelve hours. The pats made to test the soundness may be used in determining the time of setting. The cement is considered to have acquired its initial set when the pat will bear, without being appreciably indented, a wire $\frac{1}{12}$ inch in diameter loaded to weigh one fourth pound. The final set has been acquired when the pat will bear, without being appreciably indented, a needle $\frac{1}{24}$ inch in diameter loaded to weigh one pound.

14. *Making briquettes.* — In making briquettes, neat cement mortar of normal consistency will be used. The mortar will be thoroughly mixed with a trowel and kneaded into the moulds with the thumbs, a blunt stick, or a plunger. Six briquettes will be made from each sample. In making sand briquettes, the proportions shall be one part by weight of cement to three parts of standard

crushed quartz sand and about half as much water as is used for neat briquettes. Six briquettes will be made from each sample.

15. *Tensile strength.*—The neat briquettes prepared as specified above shall stand a minimum tensile strain per square inch as follows:

For 1 day in air and 6 days in water.............	450 lbs.
" 1 " " " " 27 " " "	550 "

The sand-mortar briquettes, prepared as specified above, shall stand a minimum tensile strain per square inch as follows:

After 1 day in air and 6 days in water...........	175 lbs.
" 1 " " " " 27 " " "	225 "

16. *Requirements.*—The above are to be considered the minimum requirements. The neat tests are to be considered of less value than those of sand and cement. The twenty-eight-day tests must always be higher than the seven-day tests. A cement may be rejected which fails to meet any of the above requirements.

D.

SPECIFICATIONS FOR MUNICIPAL WORK IN PHILADELPHIA. DEPARTMENT OF PUBLIC WORKS.

BUREAU OF SURVEYS.

GEORGE S. WEBSTER, *Chief Engineer.*

Kind and weight.—Portland cement only shall be used. Barrels shall contain 376 lbs. net. Bags shall contain 94 lbs. net each.

Inspection.—All cement must be inspected. The contractor must submit the cement, and afford every facility for inspection and testing, at least 12 days before desiring to use it. The chief engineer shall be notified at once upon receipt of each shipment at the work. No cement to be used unless delivered in suitable packages properly branded.

Protection.—The cement must be protected in a suitable building having a wooden floor or platform raised from the ground, and may be reinspected at any time.

Failure of brand.—The failure of a shipment of cement on any work to meet the following requirements may prohibit further use of the same brand on that work. Rejected cement must be immediately removed from the work.

Quality.—The acceptance or rejection of a cement to be used shall rest with the chief engineer, and will be based on the following requirements:

Specific gravity. Not less than 3.1.

Ultimate tensile strength:

7 days (1 day in air, 6 days in water)	500 lbs.
28 " (1 " " " 27 " " ")	600 "
7 days (1 day in air, 6 days in water) 1 part of cement to 3 parts standard quartz sand.	170 lbs.
28 days (1 day in air, 27 days in water) 1 part of cement to 3 parts standard quartz sand.	240 lbs.

Fineness.—Residue on No. 100 sieve not over 8 per cent by weight.

Residue on No. 200 sieve not over 25 per cent by weight.

Set.—It shall require at least 20 minutes to develop

initial set, and shall develop hard set in not less than 1 hour nor more than 10 hours, this being determined by means of the Vicat needle on pastes of cement of normal consistency at temperature as near 70° Fahr. as practicable.

Constancy of volume.— Pats of cement 3 inches in diameter, one half inch thick at centre, tapering to thin edge, immersed in water after 24 hours in moist air, shall show no signs of cracking, distortion or disintegration. Similar pats in air shall also remain sound and hard.

Sulphuric anhydride (SO_3). Not more than 1.75 per cent.

Magnesia (MgO).—Not more than 4 per cent.

Briquettes for testing shall be 1 sq. in. area of cross-section; sieves shall be of brass-wire cloth having approximately 9800 and 37,500 meshes per sq. in. respectively, the diameter of wire being .0045 and .0023 respectively.

Additional requirements.—All cements shall meet such additional requirements as to chemical and accelerated tests as the chief engineer may determine. The requirements for "set" may be modified where the conditions are such as to make it advisable.

E.

CHICAGO, MILWAUKEE AND ST. PAUL RAILWAY COMPANY. BRIDGE AND BUILDING DEPARTMENT.

SPECIFICATIONS FOR PORTLAND CEMENT.

CHICAGO, Nov. 28, 1904.

Portland cement will be sampled in such a way as to indicate the average quality of cement in the car. Such samples will be tested in the Company's Laboratory, and must conform to the Standard Specifications for Portland Cement, adopted by the Committee of the American Society for Testing Materials in June, 1904, except as to the "General Conditions," Paragraphs 1 to 10, and "Tensile Strength," which will be as specified below. The methods of testing are those recommended in the revised reports of the Special Committee "On Uniform Tests of Cement," of the American Society of Civil Engineers, in January, 1904.

Specific Gravity, Fineness, Time of Setting, Constancy of Volume, and Amount of Sulphuric Acid and Magnesia correspond with the specifications of the "American Society for Testing Materials," above referred to.

TENSILE STRENGTH.

The minimum requirements for tensile strength for briquettes 1 inch square in section shall be as follows: The neat tests shall show no retrogression in strength within the period specified and the sand tests shall show an increase of at least 15% between 7- and 28-day tests.

Neat Test:

24 hours in moist air		150 lbs.
7 days (1 day in moist air and 6 days in water)		500 "
28 " (1 " " " " " 27 " " ")		600 "

Sand Test (one part cement to three parts sand):

7 days (1 day in moist air and 6 days in water)		175 lbs.
28 " (1 " " " " " 27 " " ")		250 "

GENERAL CONDITIONS.

Cement shall be uniform in color, free from lumps and foreign substances, and shall have been properly aged.

Cement shall be delivered in suitable packages with the brand and the name of the manufacturer plainly marked thereon.

A bag of cement shall contain 94 lbs. cement net. One barrel of Portland cement shall contain four bags.

The tests made by the Railway Company shall be final. The Engineer and Superintendent of Bridges and Buildings reserves the right to reject, on the first seven-day test, any shipment of cement because of failure to meet the above requirements, or for any other cause which he may deem sufficient.

Cement rejected on account of failure to meet the above requirements will be held subject to the order of the shipper and at his expense for freight charges to and from the point where the cement was to have been used.

J. C. HAIN,
Engr. Mas. Const.

Approved:
C. F. LOWETH,
Engr. and Supt. B. and B.

SPECIFICATIONS OF THE AMERICAN SOCIETY FOR TESTING MATERIALS FOR PORTLAND CEMENT.

REFERRED TO IN THE SECOND PARAGRAPH OF "SPECIFICATIONS FOR PORTLAND CEMENT" OF THE CHICAGO, MILWAUKEE AND ST. PAUL RAILWAY COMPANY, UNDER DATE OF NOV. 28, 1904.

SPECIFIC GRAVITY.

The specific gravity of the cement, thoroughly dried at 100° C., shall not be less than 3.10.

FINENESS.

It shall leave by weight a residue of not more than 8% on the No. 100, and not more than 45% on the No. 200 sieve.

TIME OF SETTING.

It shall develop initial set in not less than thirty minutes, but must develop hard set in not less than one hour, nor more than ten hours.

CONSTANCY OF VOLUME.

Pats of neat cement about three inches in diameter, one half inch thick at the centre, and tapering to a thin edge, shall be kept in moist air for a period of twenty-four hours.

A pat is then kept in air at normal temperature and observed at intervals for at least 28 days.

Another pat is kept in water maintained as near 70° Fahr. as practicable, and observed at intervals for at least 28 days.

A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for five hours.

These pats, to satisfactorily pass the requirements, shall remain firm and hard, and show no signs of distortion, checking, cracking, or disintegrating.

SULPHURIC ACID AND MAGNESIA.

The cement shall not contain more than 1.75% of anhydrous sulphuric acid (SO), nor more than 4% of magnesia (MgO).

J. C. HAIN,
Engr. Mas. Const.

Approved:
C. F. LOWETH,
Engr. and Supt. B. and B.

F.

SPECIFICATIONS FOR MUNICIPAL WORK AT WASHINGTON, D. C.

A. W. DOW, *Inspector of Asphalts and Cements.*

PORTLAND CEMENT.

Fineness.—Not less than 95 per cent to pass a 50-mesh sieve, and not less than 90 per cent through a 100-mesh sieve.

Time of setting.—Initial set, in not less than 45 minutes,

when mixed with the smallest amount of water between the temperature of 70° and 80° Fahr., except when a quick-setting cement is desired, in which case the time of setting will be given by the Commissioners.

Tensile strength:

1 day (in air until hard set, rest of day in water):	
Neat cement	225 lbs.
7 days (in air 1 day, in water 6 days):	
Neat cement	450 lbs.
Three parts sand	175 "
28 days (in air 1 day, in water 27 days):	
Neat cement	550 lbs.
Three parts sand	225 "

When made neat into wedge-shaped pats about three inches upon a side, half an inch thick at back tapering to a feather edge, the cement must show no signs of cracking or warping after being in air or water at normal temperature for 28 days.

Any cement which shows signs of swelling after being mixed will be rejected.

All cement must be properly seasoned; too fresh cement or stale cement will be rejected.

No cement shall contain over 2 per cent of sulphuric acid (SO_3).

Class A. Portland.—Cement furnished under this classification must comply with the preceding specifications.

Class B. Portland.—Cement furnished under this classification must comply with the preceding specifications, and in addition must meet the following requirements; Class B cement is intended for special use in the

Sewer Department, D. C. In awarding contract for this cement the brand considered best adapted for the use intended will be selected. Brands of cement which are believed to attain such strength and hardness that centres and forms may be satisfactorily drawn within 24 hours after placing a concrete made of cement one part, sand three parts, broken stone three parts, and pebbles three parts, when the temperature is at or above 40° Fahr., may be accepted as Class B cement.

3. *Sample.*—Each bidder must deliver at D. C. Cement House prior to time of opening proposals, a sample barrel of the cement which he proposes to furnish.

4. *Package.*—Portland cement delivered in wood will be packed in new, strong, serviceable barrels, lined with paper. Weight to be 400 pounds gross, and the weight of the cement to be not less than 375 pounds. Portland cement delivered in sacks will be packed in strong, serviceable canvas sacks, containing one fourth of the quantity specified to be delivered in barrel. The bags will be returned to the contractor or paid for at the rate of 10 cents each. All sacks will be subject to inspection and approval by the Commissioners.

5. *Place of delivery.*—Cement will be delivered at D. C. Warehouse, located on Canal street, between Delaware avenue and First street S. W., or F. O. B. cars on lines of Baltimore and Ohio, or Philadelphia, Baltimore and Washington Railroads, at such points as may be specified by the Commissioners, D. C.

6. *Time.*—Delivery must be commenced within thirty days after notice of award of contract and prosecuted at such a rate, not exceeding one fifth of the total amount of contract in any one month, as may be ordered in

writing by the Commissioners, D. C. Failure to comply with this requirement will be authority for the Commissioners to suspend or to wholly annul contract; or to purchase the cement in arrears (or such less quantity as may be required) in open market, in which event any increased cost over and above contract rates will be charged against the contractor in default and deducted from any moneys that may be due or may become due to him. The right is also reserved to the Commissioners, in addition to the remedies prescribed above, to charge against the contractor and deduct from any moneys due or which may thereafter become due, the sum of ten dollars per diem (Sundays and legal holidays not included), estimated as liquidated and fixed damages arising from contractor's failure to properly perform the terms of his contract.

7. *Inspection.*—Cement will be sampled after delivery. In all cases the seven-day test herein provided will be made before final acceptance, but the right to reject shall not be waived at any time before final payment or the use of the cement in question. All tests will be made by the methods prescribed by the committee of the American Society of Civil Engineers, with such modifications as are employed in the laboratory of the Engineer Department, and which are open to the inspection of the contractors. All cements will, from time to time, be subjected to chemical analysis, and must show freedom from any foreign substance or deleterious matter, and that the elements are combined in proper proportions to secure the best results and insure permanency. All cements must be of uniform quality and satisfactory to the Commissioners. The works of the

contractor shall at all times be open to the inspection of the Commissioners. It will be the duty of the inspector to point out any disregard of the specifications. Any employee of the contractors who shall use profane or abusive language to the inspector or other representative of the District or otherwise impede or embarrass him in the discharge of his duties shall be immediately removed by the contractor, and not again employed without the consent of the Commissioners. Should the conduct or methods of the contractor require additional inspectors, they will be appointed and the cost thereof, not exceeding $4.00 per diem (of ten hours) for each inspector, will be charged against the contractor.

NATURAL CEMENT.

Fineness.—Not less than 95 per cent, to pass a 50-mesh sieve, and not less than 82 per cent through a 100-mesh sieve.

Time of setting.—Initial set, in not less than 10 nor more than 30 minutes, when mixed with the smallest amount of water between the temperatures of 70° and 80° Fahr.

Tensile strength:

1 day (in air until hard set, rest of day in water):
  Neat cement........................ 80 lbs.
7 days (in air 1 day, in water 6 days):
  Neat cement........................ 150 lbs.
  Two parts sand..................... 80 "
28 days (in air 1 day, in water 27 days):
  Neat cement........................ 200 lbs.
  Two parts sand..................... 150 "

When made neat into wedge-shaped pats about three inches upon a side, half an inch thick at back, tapering to a feather edge, the cement must show no signs of cracking or warping after being in air or water at normal temperature for 28 days.

Any cement which shows signs of swelling after being mixed will be rejected.

All cement must be properly seasoned; too fresh cement or stale cement will be rejected.

No cement shall contain over 2 per cent of sulphuric acid (SO_3).

3. *Sample.*—Each bidder must deliver at D. C. Cement House prior to time of opening proposals, a sample barrel or sack of the cement which he proposes to furnish.

4. *Package.*—Natural hydraulic cement will be packed in strong, serviceable canvas sacks of uniform size. The bags will be returned to the contractor or paid for at the rate of 8 cents each for small sacks and 10 cents for large sacks. All sacks will be subject to inspection and approval by the Commissioners.

5. *Weights.*—Natural cement will be paid for at the rate of 300 pounds net per barrel. Each sack will contain 100 or 150 pounds. The contractor will be required to deliver cement in sacks of uniform size, and bidder will state whether it is proposed to furnish cement in 100-pound sacks or in 150-pound sacks.

INDEX.

SHORT-TITLE CATALOGUE

OF THE

PUBLICATIONS

OF

JOHN WILEY & SONS,

NEW YORK.

LONDON: CHAPMAN & HALL, LIMITED.

ARRANGED UNDER SUBJECTS.

Descriptive circulars sent on application. Books marked with an asterisk (*) are sold at *net* prices only, a double asterisk (**) books sold under the rules of the American Publishers' Association at *net* prices subject to an extra charge for postage. All books are bound in cloth unless otherwise stated.

AGRICULTURE.

Armsby's Manual of Cattle-feeding....12mo, $1 75
  Principles of Animal Nutrition....8vo, 4 00
Budd and Hansen's American Horticultural Manual:
  Part I. Propagation, Culture, and Improvement....12mo, 1 50
  Part II. Systematic Pomology....12mo, 1 50
Downing's Fruits and Fruit-trees of America....8vo, 5 00
Elliott's Engineering for Land Drainage....12mo, 1 50
  Practical Farm Drainage....12mo, 1 00
Green's Principles of American Forestry....12mo, 1 50
Grotenfelt's Principles of Modern Dairy Practice. (Woll.)....12mo, 2 00
Kemp's Landscape Gardening....12mo, 2 50
Maynard's Landscape Gardening as Applied to Home Decoration....12mo, 1 50
Sanderson's Insects Injurious to Staple Crops....12mo, 1 50
  Insects Injurious to Garden Crops. (In preparation.)
  Insects Injuring Fruits. (In preparation.)
Stockbridge's Rocks and Soils....8vo, 2 50
Woll's Handbook for Farmers and Dairymen....16mo, 1 50

ARCHITECTURE.

Baldwin's Steam Heating for Buildings....12mo, 2 50
Bashore's Sanitation of a Country House....12mo, 1 00
Berg's Buildings and Structures of American Railroads....4to, 5 00
Birkmire's Planning and Construction of American Theatres....8vo, 3 00
  Architectural Iron and Steel....8vo, 3 50
  Compound Riveted Girders as Applied in Buildings....8vo, 2 00
  Planning and Construction of High Office Buildings....8vo 3 50
  Skeleton Construction in Buildings....8vo, 3 00
Brigg's Modern American School Buildings....8vo, 4 00
Carpenter's Heating and Ventilating of Buildings....8vo, 4 00
Freitag's Architectural Engineering....8vo, 3 50
  Fireproofing of Steel Buildings....8vo, 2 50
French and Ives's Stereotomy....8vo, 2 50
Gerhard's Guide to Sanitary House-inspection....16mo, 1 00
  Theatre Fires and Panics....12mo, 1 50
Holly's Carpenters' and Joiners' Handbook....18mo, 75
Johnson's Statics by Algebraic and Graphic Methods....8vo, 2 00

Kidder's Architects' and Builders' Pocket-book. Rewritten Edition. 16mo, mor., 5 00
Merrill's Stones for Building and Decoration.........................8vo, 5 00
Non-metallic Minerals: Their Occurrence and Uses..............8vo, 4 00
Monckton's Stair-building..4to, 4 00
Patton's Practical Treatise on Foundations..........................8vo, 5 00
Peabody's Naval Architecture...8vo, 7 50
Richey's Handbook for Superintendents of Construction.........16mo, mor, 4 00
Sabin's Industrial and Artistic Technology of Paints and Varnish........8vo, 3 00
Siebert and Biggin's Modern Stone-cutting and Masonry...............8vo, 1 50
Snow's Principal Species of Wood.......................................8vo, 3 50
Sondericker's Graphic Statics with Applications to Trusses, Beams, and Arches. 8vo, 2 00
Towne's Locks and Builders' Hardware..................18mo, morocco, 3 00
Wait's Engineering and Architectural Jurisprudence..................8vo, 6 00
Sheep, 6 50
Law of Operations Preliminary to Construction in Engineering and Architecture..8vo, 5 00
Sheep, 5 50
Law of Contracts...8vo, 3 00
Wood's Rustless Coatings: Corrosion and Electrolysis of Iron and Steel..8vo, 4 00
Woodbury's Fire Protection of Mills......................................8vo, 2 50
Worcester and Atkinson's Small Hospitals, Establishment and Maintenance, Suggestions for Hospital Architecture, with Plans for a Small Hospital. 12mo, 1 25
The World's Columbian Exposition of 1893......................Large 4to, 1 00

ARMY AND NAVY.

Bernadou's Smokeless Powder, Nitro-cellulose, and the Theory of the Cellulose Molecule...12mo, 2 50
* Bruff's Text-book Ordnance and Gunnery..........................8vo, 6 00
Chase's Screw Propellers and Marine Propulsion......................8vo, 3 00
Cloke's Gunner's Examiner...8vo, 1 50
Craig's Azimuth..4to, 3 50
Crehore and Squier's Polarizing Photo-chronograph..................8vo, 3 00
Cronkhite's Gunnery for Non-commissioned Officers........24mo, morocco, 2 00
* Davis's Elements of Law...8vo, 2 50
* Treatise on the Military Law of United States..................8vo, 7 00
Sheep, 7 50
De Brack's Cavalry Outposts Duties. (Carr.)..............24mo, morocco, 2 00
Dietz's Soldier's First Aid Handbook.......................16mo, morocco, 1 25
* Dredge's Modern French Artillery....................4to, half morocco, 15 00
Durand's Resistance and Propulsion of Ships..........................8vo, 5 00
* Dyer's Handbook of Light Artillery....................................12mo, 3 00
Eissler's Modern High Explosives..8vo, 4 00
* Fiebeger's Text-book on Field Fortification..................Small 8vo, 2 00
Hamilton's The Gunner's Catechism 18mo, 1 00
* Hoff's Elementary Naval Tactics..8vo, 1 50
Ingalls's Handbook of Problems in Direct Fire..........................8vo, 4 00
* Ballistic Tables..8vo, 1 50
* Lyons's Treatise on Electromagnetic Phenomena. Vols. I. and II..8vo, each, 6 00
* Mahan's Permanent Fortifications. (Mercur.)..........8vo, half morocco, 7 50
Manual for Courts-martial....................................16mo, morocco, 1 50
* Mercur's Attack of Fortified Places.....................................12mo, 2 00
* Elements of the Art of War...8vo, 4 00
Metcalf's Cost of Manufactures—And the Administration of Workshops..8vo, 5 00
* Ordnance and Gunnery. 2 vols...12mo, 5 00
Murray's Infantry Drill Regulations..........................18mo, paper, 10
Nixon's Adjutants' Manual..24mo, 1 00
Peabody's Naval Architecture..8vo, 7 50

* Phelps's Practical Marine Surveying..............................8vo, 2 50
Powell's Army Officer's Examiner..............................12mo, 4 00
Sharpe's Art of Subsisting Armies in War..................18mo. morocco, 1 50
* Walke's Lectures on Explosives..............................8vo, 4 00
* Wheeler's Siege Operations and Military Mining....................8vo, 2 00
Winthrop's Abridgment of Military Law..............................12mo, 2 50
Woodhull's Notes on Military Hygiene..............................16mo, 1 50
Young's Simple Elements of Navigation..................16mo, morocco, 1 00
Second Edition, Enlarged and Revised..................16mo, morocco, 2 00

ASSAYING.

Fletcher's Practical Instructions in Quantitative Assaying with the Blowpipe. 12mo, morocco, 1 50
Furman's Manual of Practical Assaying..............................8vo, 3 00
Lodge's Notes on Assaying and Metallurgical Laboratory Experiments....8vo, 3 00
Miller's Manual of Assaying..............................12mo, 1 00
O'Driscoll's Notes on the Treatment of Gold Ores..............................8vo, 2 00
Ricketts and Miller's Notes on Assaying..............................8vo, 3 00
Ulke's Modern Electrolytic Copper Refining..............................8vo, 3 00
Wilson's Cyanide Processes..............................12mo, 1 50
Chlorination Process..............................12mo, 1 50

ASTRONOMY.

Comstock's Field Astronomy for Engineers..............................8vo, 2 50
Craig's Azimuth..............................4to, 3 50
Doolittle's Treatise on Practical Astronomy..............................8vo, 4 00
Gore's Elements of Geodesy..............................8vo, 2 50
Hayford's Text-book of Geodetic Astronomy..............................8vo, 3 00
Merriman's Elements of Precise Surveying and Geodesy..............8vo, 2 50
* Michie and Harlow's Practical Astronomy..............................8vo, 3 00
* White's Elements of Theoretical and Descriptive Astronomy........12mo, 2 00

BOTANY.

Davenport's Statistical Methods, with Special Reference to Biological Variation. 16mo, morocco, 1 25
Thomé and Bennett's Structural and Physiological Botany............16mo, 2 25
Westermaier's Compendium of General Botany. (Schneider.)..........8vo, 2 00

CHEMISTRY.

Adriance's Laboratory Calculations and Specific Gravity Tables........12mo, 1 25
Allen's Tables for Iron Analysis..............................8vo, 3 00
Arnold's Compendium of Chemistry. (Mandel.)................Small 8vo, 3 50
Austen's Notes for Chemical Students..............................12mo, 1 50
Bernadou's Smokeless Powder.—Nitro-cellulose, and Theory of the Cellulose Molecule..............................12mo, 2 50
Bolton's Quantitative Analysis..............................8vo, 1 50
* Browning's Introduction to the Rarer Elements..............................8vo, 1 50
Brush and Penfield's Manual of Determinative Mineralogy..............8vo, 4 00
Classen's Quantitative Chemical Analysis by Electrolysis. (Boltwood.)..8vo, 3 00
Cohn's Indicators and Test-papers..............................12mo, 2 00
Tests and Reagents..............................8vo, 3 00
Crafts's Short Course in Qualitative Chemical Analysis. (Schaeffer.)...12mo, 1 50
Dolezalek's Theory of the Lead Accumulator (Storage Battery). (Von Ende.)..............................12mo, 2 50
Drechsel's Chemical Reactions. (Merrill.)..............................12mo, 1 25
Duhem's Thermodynamics and Chemistry. (Burgess.)................8vo, 4 00
Eissler's Modern High Explosives..............................8vo, 4 00
Effront's Enzymes and their Applications. (Prescott.)................8vo, 3 00
Erdmann's Introduction to Chemical Preparations. (Dunlap.)........12mo, 1 25

Fletcher's Practical Instructions in Quantitative Assaying with the Blowpipe.
12mo, morocco, 1 50

Fowler's Sewage Works Analyses..........12mo. 2 00

Fresenius's Manual of Qualitative Chemical Analysis. (Wells.)..........8vo, 5 00

Manual of Qualitative Chemical Analysis. Part I. Descriptive. (Wells.) 8vo, 3 00

System of Instruction in Quantitative Chemical Analysis. (Cohn.) 2 vols..........8vo, 12 50

Fuertes's Water and Public Health..........12mo, 1 50

Furman's Manual of Practical Assaying..........8vo, 3 00

* Getman's Exercises in Physical Chemistry..........12mo, 2 00

Gill's Gas and Fuel Analysis for Engineers..........12mo, 1 25

Grotenfelt's Principles of Modern Dairy Practice. (Woll.)..........12mo, 2 00

Hammarsten's Text-book of Physiological Chemistry. (Mandel.)..........8vo, 4 00

Helm's Principles of Mathematical Chemistry. (Morgan.)..........12mo, 1 50

Hering's Ready Reference Tables (Conversion Factors)..........16mo morocco, 2 50

Hind's Inorganic Chemistry..........8vo, 3 00

* Laboratory Manual for Students..........12mo, 1 00

Holleman's Text-book of Inorganic Chemistry. (Cooper.)..........8vo, 2 50

Text-book of Organic Chemistry. (Walker and Mott.)..........8vo, 2 50

* Laboratory Manual of Organic Chemistry. (Walker.)..........12mo, 1 00

Hopkins's Oil-chemists' Handbook..........8vo, 3 00

Jackson's Directions for Laboratory Work in Physiological Chemistry..8vo, 1 25

Keep's Cast Iron..........8vo, 2 50

Ladd's Manual of Quantitative Chemical Analysis..........12mo, 1 00

Landauer's Spectrum Analysis. (Tingle.)..........8vo, 3 00

* Langworthy and Austen. The Occurrence of Aluminium in Vegeable Products, Animal Products, and Natural Waters..........8vo, 2 00

Lassar-Cohn's Practical Urinary Analysis. (Lorenz.)..........12mo, 1 00

Application of Some General Reactions to Investigations in Organic Chemistry. (Tingle.)..........12mo, 1 00

Leach's The Inspection and Analysis of Food with Special Reference to State Control..........8vo, 7 50

Löb's Electrolysis and Electrosynthesis of Organic Compounds. (Lorenz.).12mo, 1 00

Lodge's Notes on Assaying and Metallurgical Laboratory Experiments....8vo, 3 00

Lunge's Techno-chemical Analysis. (Cohn.)..........12mo, 1 00

Mandel's Handbook for Bio-chemical Laboratory..........12mo, 1 50

* Martin's Laboratory Guide to Qualitative Analysis with the Blowpipe..12mo, 60

Mason's Water-supply. (Considered Principally from a Sanitary Standpoint.) 3d Edition, Rewritten..........8vo, [illegible] 00

Examination of Water. (Chemical and Bacteriological.)..........12mo, 1 25

Matthew's The Textile Fibres..........8vo, 3 50

Meyer's Determination of Radicles in Carbon Compounds. (Tingle.)..12mo, 1 00

Miller's Manual of Assaying..........12mo, 1 00

Mixter's Elementary Text-book of Chemistry..........12mo, 1 50

Morgan's Outline of Theory of Solution and its Results..........12mo, 1 00

Elements of Physical Chemistry..........12mo, 2 00

Morse's Calculations used in Cane-sugar Factories..........16mo, morocco, 1 50

Mulliken's General Method for the Identification of Pure Organic Compounds. Vol. I..........Large 8vo, 5 00

O'Brine's Laboratory Guide in Chemical Analysis..........8vo, 2 00

O'Driscoll's Notes on the Treatment of Gold Ores..........8vo, 2 00

Ostwald's Conversations on Chemistry. Part One (Ramsey.)..........12mo, 1 50

Ostwald's Conversations on Chemistry. Part Two. (Turnbull). (In Press.)

* Penfield's Notes on Determinative Mineralogy and Record of Mineral Tests.
8vo, paper, 50

Pictet's The Alkaloids and their Chemical Constitution. (Biddle.)..........8vo, 5 00

Pinner's Introduction to Organic Chemistry. (Austen.)..........12mo, 1 50

Poole's Calorific Power of Fuels..........8vo, 3 00

Prescott and Winslow's Elements of Water Bacteriology, with Special Reference to Sanitary Water Analysis..........12mo, 1 25

* Reisig's Guide to Piece-dyeing. 8vo, 25 00
Richards and Woodman's Air, Water, and Food from a Sanitary Standpoint 8vo, 2 00
Richards's Cost of Living as Modified by Sanitary Science. 12mo, 1 00
Cost of Food, a Study in Dietaries 12mo, 1 00
* Richards and Williams's The Dietary Computer. 8vo, 1 50
Ricketts and Russell's Skeleton Notes upon Inorganic Chemistry. (Part I. Non-metallic Elements.). . . . . .8vo, morocco, 75
Ricketts and Miller's Notes on Assaying. 8vo, 3 00
Rideal's Sewage and the Bacterial Purification of Sewage. 8vo, 3 50
Disinfection and the Preservation of Food. 8vo, 4 00
Rigg's Elementary Manual for the Chemical Laboratory. 8vo, 1 25
Rostoski's Serum Diagnosis. (Bolduan.). 12mo, 1 00
Ruddiman's Incompatibilities in Prescriptions. 8vo, 2 00
Sabin's Industrial and Artistic Technology of Paints and Varnish. 8vo, 3 00
Salkowski's Physiological and Pathological Chemistry. (Orndorff.). 8vo, 2 50
Schimpf's Text-book of Volumetric Analysis. 12mo, 2 50
Essentials of Volumetric Analysis. 12mo, 1 25
Spencer's Handbook for Chemists of Beet-sugar Houses. . . . .16mo, morocco, 3 00
Handbook for Sugar Manufacturers and their Chemists. .16mo, morocco, 2 00
Stockbridge's Rocks and Soils. 8vo, 2 50
* Tillman's Elementary Lessons in Heat. 8vo, 1 50
* Descriptive General Chemistry. 8vo, 3 00
Treadwell's Qualitative Analysis. (Hall.). 8vo, 3 00
Quantitative Analysis. (Hall.). 8vo, 4 00
Turneaure and Russell's Public Water-supplies. 8vo, 5 00
Van Deventer's Physical Chemistry for Beginners. (Boltwood.) 12mo, 1 50
* Walke's Lectures on Explosives. 8vo, 4 00
Washington's Manual of the Chemical Analysis of Rocks. 8vo, 2 00
Wassermann's Immune Sera: Hæmolysins, Cytotoxins, and Precipitins. (Bolduan.) 12mo, 1 00
Well's Laboratory Guide in Qualitative Chemical Analysis. 8vo, 1 50
Short Course in Inorganic Qualitative Chemical Analysis for Engineering Students. 12mo, 1 50
Text-book of Chemical Arithmetic 12mo, 1 25
Whipple's Microscopy of Drinking-water. 8vo, 3 50
Wilson's Cyanide Processes 12mo, 1 50
Chlorination Process. 12mo, 1 50
Wulling's Elementary Course in Inorganic, Pharmaceutical, and Medical Chemistry. 12mo, 2 00

CIVIL ENGINEERING.

BRIDGES AND ROOFS. HYDRAULICS. MATERIALS OF ENGINEERING. RAILWAY ENGINEERING.

Baker's Engineers' Surveying Instruments. 12mo, 3 00
Bixby's Graphical Computing Table. . . . . .Paper 19½ × 24¼ inches. 25
** Burr's Ancient and Modern Engineering and the Isthmian Canal. (Postage, 27 cents additional.). 8vo, 3 50
Comstock's Field Astronomy for Engineers. 8vo, 2 50
Davis's Elevation and Stadia Tables. 8vo, 1 00
Elliott's Engineering for Land Drainage. 12mo, 1 50
Practical Farm Drainage. 12mo, 1 00
*Fiebeger's Treatise on Civil Engineering. 8vo, 5 00
Folwell's Sewerage. (Designing and Maintenance.). 8vo, 3 00
Freitag's Architectural Engineering. 2d Edition, Rewritten 8vo, 3 50
French and Ives's Stereotomy. 8vo, 2 50
Goodhue's Municipal Improvements. 12mo, 1 75
Goodrich's Economic Disposal of Towns' Refuse. .8vo, 3 50
Gore's Elements of Geodesy. 8vo, 2 50
Hayford's Text-book of Geodetic Astronomy. 8vo, 3 00
Hering's Ready Reference Tables (Conversion Factors). . . . . .16mo, morocco, 2 50

Howe's Retaining Walls for Earth. 12mo, 1 25
Johnson's (J. B.) Theory and Practice of Surveying. . . . . Small 8vo, 4 00
Johnson's (L. J.) Statics by Algebraic and Graphic Methods. 8vo, 2 00
Laplace's Philosophical Essay on Probabilities. (Truscott and Emory.). 12mo, 2 00
Mahan's Treatise on Civil Engineering. (1873.) (Wood.). 8vo, 5 00
* Descriptive Geometry. 8vo, 1 50
Merriman's Elements of Precise Surveying and Geodesy. 8vo, 2 50
Elements of Sanitary Engineering. 8vo, 2 00
Merriman and Brooks's Handbook for Surveyors. . . . . 16mo, morocco, 2 00
Nugent's Plane Surveying. 8vo, 3 50
Ogden's Sewer Design. 12mo, 2 00
Patton's Treatise on Civil Engineering. . . . . 8vo half leather, 7 50
Reed's Topographical Drawing and Sketching 4to, 5 00
Rideal's Sewage and the Bacterial Purification of Sewage. 8vo, 3 50
Siebert and Biggin's Modern Stone-cutting and Masonry. 8vo, 1 50
Smith's Manual of Topographical Drawing. (McMillan.). 8vo, 2 50
Sondericker's Graphic Statics, with Applications to Trusses, Beams, and Arches. 8vo, 2 00
Taylor and Thompson's Treatise on Concrete, Plain and Reinforced. 8vo, 5 00
* Trautwine's Civil Engineer's Pocket-book. . . . . 16mo, morocco, 5 00
Wait's Engineering and Architectural Jurisprudence. 8vo, 6 00
Sheep, 6 50
Law of Operations Preliminary to Construction in Engineering and Architecture. 8vo, 5 00
Sheep, 5 50
Law of Contracts. 8vo, 3 00
Warren's Stereotomy—Problems in Stone-cutting. 8vo, 2 50
Webb's Problems in the Use and Adjustment of Engineering Instruments. 16mo, morocco, 1 25
* Wheeler s Elementary Course of Civil Engineering. 8vo, 4 00
Wilson's Topographic Surveying. 8vo, 3 50

BRIDGES AND ROOFS.

Boller's Practical Treatise on the Construction of Iron Highway Bridges. . 8vo, 2 00
* Thames River Bridge. . . . . 4to, paper, 5 00
Burr's Course on the Stresses in Bridges and Roof Trusses, Arched Ribs, and Suspension Bridges. 8vo, 3 50
Burr and Falk's Influence Lines for Bridge and Roof Computations. . . . 8vo, 3 00
Du Bois's Mechanics of Engineering. Vol. II. Small 4to, 10 00
Foster's Treatise on Wooden Trestle Bridges. 4to, 5 00
Fowler's Ordinary Foundations. 8vo, 3 50
Greene's Roof Trusses. 8vo, 1 25
Bridge Trusses. 8vo, 2 50
Arches in Wood, Iron, and Stone. 8vo, 2 50
Howe's Treatise on Arches. 8vo, 4 00
Design of Simple Roof-trusses in Wood and Steel. 8vo, 2 00
Johnson, Bryan, and Turneaure's Theory and Practice in the Designing of Modern Framed Structures. . . . . Small 4to, 10 00
Merriman and Jacoby's Text-book on Roofs and Bridges:
Part I. Stresses in Simple Trusses. 8vo, 2 50
Part II. Graphic Statics. 8vo, 2 50
Part III. Bridge Design. 8vo, 2 50
Part IV. Higher Structures. 8vo, 2 50
Morison's Memphis Bridge. 4to, 10 00
Waddell's De Pontibus, a Pocket-book for Bridge Engineers. . 16mo, morocco, 3 00
Specifications for Steel Bridges. 12mo. 1 25
Wood's Treatise on the Theory of the Construction of Bridges and Roofs. . 8vo, 2 00
Wright's Designing of Draw-spans:
Part I. Plate-girder Draws. 8vo, 2 50
Part II. Riveted-truss and Pin-connected Long-span Draws. 8vo, 2 50
Two parts in one volume. 8vo, 3 50

HYDRAULICS.

Bazin's Experiments upon the Contraction of the Liquid Vein Issuing from an Orifice. (Trautwine.)	8vo,	2 00
Bovey's Treatise on Hydraulics	8vo,	5 00
Church's Mechanics of Engineering	8vo,	6 00
Diagrams of Mean Velocity of Water in Open Channels	paper,	1 50
Coffin's Graphical Solution of Hydraulic Problems	16mo, morocco,	2 50
Flather's Dynamometers, and the Measurement of Power	12mo,	3 00
Folwell's Water-supply Engineering	8vo,	4 00
Frizell's Water-power	8vo,	5 00
Fuertes's Water and Public Health	12mo,	1 50
Water-filtration Works	12mo,	2 50
Ganguillet and Kutter's General Formula for the Uniform Flow of Water in Rivers and Other Channels. (Hering and Trautwine.)	8vo,	4 00
Hazen's Filtration of Public Water-supply	8vo,	3 00
Hazlehurst's Towers and Tanks for Water-works	8vo,	2 50
Herschel's 115 Experiments on the Carrying Capacity of Large, Riveted, Metal Conduits	8vo,	2 00
Mason's Water-supply. (Considered Principally from a Sanitary Standpoint.)	8vo,	4 00
Merriman's Treatise on Hydraulics	8vo,	5 00
* Michie's Elements of Analytical Mechanics	8vo,	4 00
Schuyler's Reservoirs for Irrigation, Water-power, and Domestic Water-supply	Large 8vo,	5 00
** Thomas and Watt's Improvement of Rivers. (Post., 44c. additional.)	4to,	6 00
Turneaure and Russell's Public Water-supplies	8vo,	5 00
Wegmann's Design and Construction of Dams	4to,	5 00
Water-supply of the City of New York from 1658 to 1895	4to,	10 00
Williams and Hazen's Hydraulic Tables	8vo,	1 50
Wilson's Irrigation Engineering	Small 8vo,	4 00
Wolff's Windmill as a Prime Mover	8vo,	3 00
Wood's Turbines	8vo,	2 50
Elements of Analytical Mechanics	8vo,	3 00

MATERIALS OF ENGINEERING.

Baker's Treatise on Masonry Construction	8vo,	5 00
Roads and Pavements	8vo,	5 00
Black's United States Public Works	Oblong 4to,	5 00
Bovey's Strength of Materials and Theory of Structures	8vo,	7 50
Burr's Elasticity and Resistance of the Materials of Engineering	8vo,	7 50
Byrne's Highway Construction	8vo,	5 00
Inspection of the Materials and Workmanship Employed in Construction.	16mo,	3 00
Church's Mechanics of Engineering	8vo,	6 00
Du Bois's Mechanics of Engineering. Vol. I.	Small 4to,	7 50
*Eckel's Cements, Limes, and Plasters	8vo,	6 00
Johnson's Materials of Construction	Large 8vo,	6 00
Fowler's Ordinary Foundations	8vo,	3 50
Keep's Cast Iron	8vo,	2 50
Lanza's Applied Mechanics	8vo,	7 50
Marten's Handbook on Testing Materials. (Henning.) 2 vols.	8vo,	7 50
Merrill's Stones for Building and Decoration	8vo,	5 00
Merriman's Mechanics of Materials.	8vo,	5 00
Strength of Materials	12mo,	1 00
Metcalf's Steel. A Manual for Steel-users	12mo,	2 00
Patton's Practical Treatise on Foundations	8vo,	5 00
Richardson's Modern Asphalt Pavements	8vo,	3 00
Richey's Handbook for Superintendents of Construction	16mo, mor.,	4 00
Rockwell's Roads and Pavements in France	12mo,	1 25

Sabin's Industrial and Artistic Technology of Paints and Varnish........8vo, 3 00
Smith's Materials of Machines.......................................12mo, 1 00
Snow's Principal Species of Wood.......................................8vo, 3 50
Spalding's Hydraulic Cement...12mo, 2 00
Text-book on Roads and Pavements.................................12mo, 2 00
Taylor and Thompson's Treatise on Concrete, Plain and Reinforced......8vo, 5 00
Thurston's Materials of Engineering. 3 Parts.............................8vo, 8 00
Part I. Non-metallic Materials of Engineering and Metallurgy.....8vo, 2 00
Part II. Iron and Steel..8vo, 3 50
Part III. A Treatise on Brasses, Bronzes, and Other Alloys and their Constituents...8vo, 2 50
Thurston's Text-book of the Materials of Construction.................8vo, 5 00
Tillson's Street Pavements and Paving Materials.......................8vo, 4 00
Waddell's De Pontibus. (A Pocket-book for Bridge Engineers.)..16mo, mor., 3 00
Specifications for Steel Bridges.....................................12mo, 1 25
Wood's (De V.) Treatise on the Resistance of Materials, and an Appendix on the Preservation of Timber.................................8vo, 2 00
Wood's (De V.) Elements of Analytical Mechanics.......................8vo, 3 00
Wood's (M. P.) Rustless Coatings: Corrosion and Electrolysis of Iron and Steel..8vo, 4 00

RAILWAY ENGINEERING.

Andrew's Handbook for Street Railway Engineers.....3x5 inches, morocco, 1 25
Berg's Buildings and Structures of American Railroads..................4to, 5 00
Brook's Handbook of Street Railroad Location.............16mo, morocco, 1 50
Butt's Civil Engineer's Field-book.......................16mo, morocco, 2 50
Crandall's Transition Curve..............................16mo, morocco, 1 50
Railway and Other Earthwork Tables..................................8vo, 1 50
Dawson's "Engineering" and Electric Traction Pocket-book..16mo, morocco, 5 00
Dredge's History of the Pennsylvania Railroad: (1879)..............Paper, 5 00
* Drinker's Tunnelling, Explosive Compounds, and Rock Drills.4to, half mor., 25 00
Fisher's Table of Cubic Yards...................................Cardboard, 25
Godwin's Railroad Engineers' Field-book and Explorers' Guide...16mo, mor., 2 50
Howard's Transition Curve Field-book.....................16mo, morocco, 1 50
Hudson's Tables for Calculating the Cubic Contents of Excavations and Embankments...8vo, 1 00
Molitor and Beard's Manual for Resident Engineers....................16mo, 1 00
Nagle's Field Manual for Railroad Engineers..............16mo, morocco, 3 00
Philbrick's Field Manual for Engineers...................16mo, morocco, 3 00
Searles's Field Engineering..............................16mo, morocco, 3 00
Railroad Spiral......................................16mo, morocco, 1 50
Taylor's Prismoidal Formulæ and Earthwork..............................8vo, 1 50
* Trautwine's Method of Calculating the Cube Contents of Excavations and Embankments by the Aid of Diagrams................................8vo, 2 00
The Field Practice of Laying Out Circular Curves for Railroads.
12mo, morocco, 2 50
Cross-section Sheet...Paper, 25
Webb's Railroad Construction.............................16mo, morocco, 5 00
Wellington's Economic Theory of the Location of Railways......Small 8vo, 5 00

DRAWING.

Barr's Kinematics of Machinery..8vo, 2 50
* Bartlett's Mechanical Drawing..8vo, 3 00
* " " " Abridged Ed..........................8vo, 1 50
Coolidge's Manual of Drawing.....................................8vo, paper 1 00
Coolidge and Freeman's Elements of General Drafting for Mechanical Engineers..Oblong 4to, 2 50
Durley's Kinematics of Machines...8vo, 4 00
Emch's Introduction to Projective Geometry and its Applications........8vo. 2 50

Hill's Text-book on Shades and Shadows, and Perspective..............8vo, 2 00
Jamison's Elements of Mechanical Drawing..........................8vo, 2 50
Advanced Mechanical Drawing..........................8vo, 2 00
Jones's Machine Design:
Part I. Kinematics of Machinery..........................8vo, 1 50
Part II. Form, Strength, and Proportions of Parts..............8vo, 3 00
MacCord's Elements of Descriptive Geometry..........................8vo, 3 00
Kinematics; or, Practical Mechanism..........................8vo, 5 00
Mechanical Drawing..........................4to, 4 00
Velocity Diagrams..........................8vo, 1 50
* Mahan's Descriptive Geometry and Stone-cutting..........................8vo, 1 50
Industrial Drawing. (Thompson.)..........................8vo, 3 50
Moyer's Descriptive Geometry..........................8vo, 2 00
Reed's Topographical Drawing and Sketching..........................4to, 5 00
Reid's Course in Mechanical Drawing..........................8vo, 2 00
Text-book of Mechanical Drawing and Elementary Machine Design.8vo, 3 00
Robinson's Principles of Mechanism..........................8vo, 3 00
Schwamb and Merrill's Elements of Mechanism..........................8vo, 3 00
Smith's Manual of Topographical Drawing. (McMillan.)..............8vo, 2 50
Warren's Elements of Plane and Solid Free-hand Geometrical Drawing.12mo, 1 00
Drafting Instruments and Operations..........................12mo, 1 25
Manual of Elementary Projection Drawing..........................12mo, 1 50
Manual of Elementary Problems in the Linear Perspective of Form and Shadow..........................12mo, 1 00
Plane Problems in Elementary Geometry..........................12mo, 1 25
Primary Geometry..........................12mo, 75
Elements of Descriptive Geometry, Shadows, and Perspective.......8vo, 3 50
General Problems of Shades and Shadows..........................8vo, 3 00
Elements of Machine Construction and Drawing..........................8vo, 7 50
Problems, Theorems, and Examples in Descriptive Geometry.......8vo, 2 50
Weisbach's Kinematics and Power of Transmission. (Hermann and Klein)8vo, 5 00
Whelpley's Practical Instruction in the Art of Letter Engraving.......12mo, 2 00
Wilson's (H. M.) Topographic Surveying..........................8vo, 3 50
Wilson's (V. T.) Free-hand Perspective..........................8vo, 2 50
Wilson's (V. T.) Free-hand Lettering..........................8vo, 1 00
Woolf's Elementary Course in Descriptive Geometry..............Large 8vo, 3 00

ELECTRICITY AND PHYSICS.

Anthony and Brackett's Text-book of Physics. (Magie.).........Small 8vo, 3 00
Anthony's Lecture-notes on the Theory of Electrical Measurements....12mo, 1 00
Benjamin's History of Electricity..........................8vo, 3 00
Voltaic Cell..........................8vo, 3 00
Classen's Quantitative Chemical Analysis by Electrolysis. (Boltwood.).8vo, 3 00
Crehore and Squier's Polarizing Photo-chronograph..........................8vo, 3 00
Dawson's "Engineering" and Electric Traction Pocket-book.16mo, morocco, 5 00
Dolezalek's Theory of the Lead Accumulator (Storage Battery). (Von Ende.)..........................12mo, 2 50
Duhem's Thermodynamics and Chemistry. (Burgess.)..............8vo, 4 00
Flather's Dynamometers, and the Measurement of Power..............12mo, 3 00
Gilbert's De Magnete. (Mottelay.)..........................8vo, 2 50
Hanchett's Alternating Currents Explained..........................12mo, 1 00
Hering's Ready Reference Tables (Conversion Factors)......16mo, morocco, 2 50
Holman's Precision of Measurements..........................8vo, 2 00
Telescopic Mirror-scale Method, Adjustments, and Tests....Large 8vo, 75
Kinzbrunner's Testing of Continuous-Current Machines..............8vo, 2 00
Landauer's Spectrum Analysis. (Tingle.)..........................8vo, 3 00
Le Chatelien's High-temperature Measurements. (Boudouard—Burgess.) 12mo, 3 00
Löb's Electrolysis and Electrosynthesis of Organic Compounds. (Lorenz.) 12mo, 1 00

* Lyons's Treatise on Electromagnetic Phenomena. Vols. I. and II. 8vo, each, 6 00
* Michie's Elements of Wave Motion Relating to Sound and Light.......8vo, 4 00
Niaudet's Elementary Treatise on Electric Batteries. (Fishback.).....12mo, 2 50
* Rosenberg's Electrical Engineering. (Haldane Gee—Kinzbrunner.)...8vo, 1 50
Ryan, Norris, and Hoxie's Electrical Machinery. Vol. I...............8vo, 2 50
Thurston's Stationary Steam-engines..................................8vo, 2 50
* Tillman's Elementary Lessons in Heat..............................8vo, 1 50
Tory and Pitcher's Manual of Laboratory Physics...............Small 8vo, 2 00
Ulke's Modern Electrolytic Copper Refining...........................8vo, 3 00

LAW.

* Davis's Elements of Law...8vo, 2 50
* Treatise on the Military Law of United States.....................8vo, 7 00
* Sheep, 7 50
Manual for Courts-martial..............................16mo, morocco, 1 50
Wait's Engineering and Architectural Jurisprudence...................8vo, 6 00
Sheep, 6 50
Law of Operations Preliminary to Construction in Engineering and Architecture..8vo, 5 00
Sheep, 5 50
Law of Contracts...8vo, 3 00
Winthrop's Abridgment of Military Law...............................12mo, 2 50

MANUFACTURES.

Bernadou's Smokeless Powder—Nitro-cellulose and Theory of the Cellulose Molecule..12mo, 2 50
Bolland's Iron Founder..12mo, 2 50
"The Iron Founder," Supplement.....................................12mo, 2 50
Encyclopedia of Founding and Dictionary of Foundry Terms Used in the Practice of Moulding...12mo, 3 00
Eissler's Modern High Explosives.....................................8vo, 4 00
Effront's Enzymes and their Applications. (Prescott.)................8vo, 3 00
Fitzgerald's Boston Machinist.......................................12mo, 1 00
Ford's Boiler Making for Boiler Makers..............................18mo, 1 00
Hopkin's Oil-chemists' Handbook......................................8vo, 3 00
Keep's Cast Iron...8vo, 2 50
Leach's The Inspection and Analysis of Food with Special Reference to State Control...Large 8vo, 7 50
Matthews's The Textile Fibres...8vo, 3 50
Metcalf's Steel. A Manual for Steel-users...........................12mo, 2 00
Metcalfe's Cost of Manufactures—And the Administration of Workshops 8vo, 5 00
Meyer's Modern Locomotive Construction................................4to, 10 00
Morse's Calculations used in Cane-sugar Factories..........16mo, morocco, 1 50
* Reisig's Guide to Piece-dyeing.....................................8vo, 25 00
Sabin's Industrial and Artistic Technology of Paints and Varnish........8vo, 3 00
Smith's Press-working of Metals.......................................8vo, 3 00
Spalding's Hydraulic Cement..12mo, 2 00
Spencer's Handbook for Chemists of Beet-sugar Houses. ... 16mo, morocco, 3 00
Handbook for Sugar Manufacturers and their Chemists..16mo, morocco, 2 00
Taylor and Thompson's Treatise on Concrete, Plain and Reinforced.....8vo, 5 00
Thurston's Manual of Steam-boilers, their Designs, Construction and Operation...8vo, 5 00
* Walke's Lectures on Explosives.....................................8vo, 4 00
Ware's Manufacture of Sugar. (In press.)
West's American Foundry Practice.....................................12mo, 2 50
Moulder's Text-book..12mo, 2 50

Wolff's Windmill as a Prime Mover 8vo, 3 00
Wood's Rustless Coatings: Corrosion and Electrolysis of Iron and Steel. .8vo, 4 00

MATHEMATICS.

Baker's Elliptic Functions..8vo, 1 50
* Bass's Elements of Differential Calculus............................12mo, 4 00
Briggs's Elements of Plane Analytic Geometry........................12mo, 1 00
Compton's Manual of Logarithmic Computations........................12mo, 1 50
Davis's Introduction to the Logic of Algebra..............................8vo, 1 50
* Dickson's College Algebra.......................................Large 12mo, 1 50
* Introduction to the Theory of Algebraic Equations. ....Large 12mo, 1 25
Emch's Introduction to Projective Geometry and its Applications........8vo, 2 50
Halsted's Elements of Geometry...8vo, 1 75
Elementary Synthetic Geometry..8vo, 1 50
Rational Geometry..12mo, 1 75
* Johnson's (J. B.) Three-place Logarithmic Tables: Vest-pocket size. paper, 15
100 copies for 5 00
* Mounted on heavy cardboard, 8 × 10 inches, 25
10 copies for 2 00
Johnson's (W. W.) Elementary Treatise on Differential Calculus. .Small 8vo, 3 00
Johnson's (W. W.) Elementary Treatise on the Integral Calculus. Small 8vo, 1 50
Johnson's (W. W.) Curve Tracing in Cartesian Co-ordinates.........12mo, 1 00
Johnson's (W. W.) Treatise on Ordinary and Partial Differential Equations.
Small 8vo, 3 50
Johnson's (W. W.) Theory of Errors and the Method of Least Squares. 12mo, 1 50
* Johnson's (W. W.) Theoretical Mechanics............................12mo, 3 00
Laplace's Philosophical Essay on Probabilities. (Truscott and Emory.). 12mo, 2 00
* Ludlow and Bass. Elements of Trigonometry and Logarithmic and Other
Tables...8vo, 3 00
Trigonometry and Tables published separately.....................Each, 2 00
* Ludlow's Logarithmic and Trigonometric Tables.......................8vo, 1 00
Maurer's Technical Mechanics...8vo, 4 00
Merriman and Woodward's Higher Mathematics..........................8vo, 5 00
Merriman's Method of Least Squares.......................................8vo, 2 00
Rice and Johnson's Elementary Treatise on the Differential Calculus. .Sm. 8vo, 3 00
Differential and Integral Calculus. 2 vols. in one...........Small 8vo, 2 50
Wood's Elements of Co-ordinate Geometry...............................8vo, 2 00
Trigonometry: Analytical, Plane, and Spherical...................12mo, 1 00

MECHANICAL ENGINEERING.

MATERIALS OF ENGINEERING, STEAM-ENGINES AND BOILERS.

Bacon's Forge Practice..12mo, 1 50
Baldwin's Steam Heating for Buildings.................................12mo, 2 50
Barr's Kinematics of Machinery...8vo, 2 50
* Bartlett's Mechanical Drawing...8vo, 3 00
* " " " Abridged Ed.......................................8vo, 1 50
Benjamin's Wrinkles and Recipes...12mo, 2 00
Carpenter's Experimental Engineering.....................................8vo, 6 00
Heating and Ventilating Buildings.......................................8vo, 4 00
Cary's Smoke Suppression in Plants using Bituminous Coal. (In Preparation.)
Clerk's Gas and Oil Engine..Small 8vo, 4 00
Coolidge's Manual of Drawing...................................8vo, paper, 1 00
Coolidge and Freeman's Elements of General Drafting for Mechanical Engineers...Oblong 4to, 2 50

Cromwell's Treatise on Toothed Gearing	12mo,	1 50
Treatise on Belts and Pulleys	12mo,	1 50
Durley's Kinematics of Machines	8vo,	4 00
Flather's Dynamometers and the Measurement of Power	12mo,	3 00
Rope Driving	12mo,	2 00
Gill's Gas and Fuel Analysis for Engineers	12mo,	1 25
Hall's Car Lubrication	12mo,	1 00
Hering's Ready Reference Tables (Conversion Factors)	16mo, morocco,	2 50
Hutton's The Gas Engine	8vo,	5 00
Jamison's Mechanical Drawing	8vo,	2 50
Jones's Machine Design:		
Part I. Kinematics of Machinery	8vo,	1 50
Part II. Form, Strength, and Proportions of Parts	8vo,	3 00
Kent's Mechanical Engineers' Pocket-book	16mo, morocco,	5 00
Kerr's Power and Power Transmission	8vo,	2 00
Leonard's Machine Shop, Tools, and Methods	8vo,	4 00
*Lorenz's Modern Refrigerating Machinery. (Pope, Haven, and Dean.)	8vo,	4 00
MacCord's Kinematics; or, Practical Mechanism	8vo,	5 00
Mechanical Drawing	4to,	4 00
Velocity Diagrams	8vo,	1 50
Mahan's Industrial Drawing. (Thompson.)	8vo,	3 50
Poole s Calorific Power of Fuels	8vo,	3 00
Reid's Course in Mechanical Drawing	8vo,	2 00
Text-book of Mechanical Drawing and Elementary Machine Design	8vo,	3 00
Richard's Compressed Air	12mo,	1 50
Robinson's Principles of Mechanism	8vo,	3 00
Schwamb and Merrill's Elements of Mechanism	8vo,	3 00
Smith's Press-working of Metals	8vo,	3 00
Thurston's Treatise on Friction and Lost Work in Machinery and Mill Work	8vo,	3 00
Animal as a Machine and Prime Motor, and the Laws of Energetics	12mo,	1 00
Warren's Elements of Machine Construction and Drawing	8vo,	7 50
Weisbach's Kinematics and the Power of Transmission. (Herrmann—Klein.)	8vo,	5 00
Machinery of Transmission and Governors. (Herrmann—Klein.)	8vo,	5 00
Wolff's Windmill as a Prime Mover	8vo,	3 00
Wood's Turbines	8vo,	2 50

MATERIALS OF ENGINEERING.

Bovey's Strength of Materials and Theory of Structures	8vo,	7 50
Burr's Elasticity and Resistance of the Materials of Engineering. 6th Edition. Reset	8vo,	7 50
Church's Mechanics of Engineering	8vo,	6 00
Johnson's Materials of Construction	8vo,	6 00
Keep's Cast Iron	8vo,	2 50
Lanza's Applied Mechanics	8vo,	7 50
Martens's Handbook on Testing Materials. (Henning.)	8vo,	7 50
Merriman's Mechanics of Materials.	8vo,	5 00
Strength of Materials	12mo,	1 00
Metcalf's Steel. A manual for Steel-users	12mo.	2 00
Sabin's Industrial and Artistic Technology of Paints and Varnish	8vo,	3 00
Smith's Materials of Machines	12mo,	1 00
Thurston's Materials of Engineering	3 vols., 8vo,	8 00
Part II. Iron and Steel	8vo,	3 50
Part III. A Treatise on Brasses, Bronzes, and Other Alloys and their Constituents	8vo,	2 50
Text-book of the Materials of Construction	8vo,	5 00

Wood's (De V.) Treatise on the Resistance of Materials and an Appendix on the Preservation of Timber. 8vo, 2 00
Wood's (De V.) Elements of Analytical Mechanics. 8vo, 3 00
Wood's (M. P.) Rustless Coatings: Corrosion and Electrolysis of Iron and Steel. 8vo, 4 00

STEAM-ENGINES AND BOILERS.

Berry's Temperature-entropy Diagram. 12mo, 1 25
Carnot's Reflections on the Motive Power of Heat. (Thurston.) 12mo, 1 50
Dawson's "Engineering" and Electric Traction Pocket-book. ....16mo, mor., 5 00
Ford's Boiler Making for Boiler Makers. 18mo, 1 00
Goss's Locomotive Sparks. 8vo, 2 00
Hemenway's Indicator Practice and Steam-engine Economy. 12mo, 2 00
Hutton's Mechanical Engineering of Power Plants. 8vo, 5 00
Heat and Heat-engines. 8vo, 5 00
Kent's Steam boiler Economy. 8vo, 4 00
Kneass's Practice and Theory of the Injector. 8vo, 1 50
MacCord's Slide-valves. 8vo, 2 00
Meyer's Modern Locomotive Construction. 4to, 10 00
Peabody's Manual of the Steam-engine Indicator. 12mo. 1 50
Tables of the Properties of Saturated Steam and Other Vapors. 8vo, 1 00
Thermodynamics of the Steam-engine and Other Heat-engines. 8vo, 5 00
Valve-gears for Steam-engines. 8vo, 2 50
Peabody and Miller's Steam-boilers. 8vo, 4 00
Pray's Twenty Years with the Indicator. ....Large 8vo, 2 50
Pupin's Thermodynamics of Reversible Cycles in Gases and Saturated Vapors. (Osterberg.) 12mo, 1 25
Reagan's Locomotives: Simple Compound, and Electric. 12mo, 2 50
Rontgen's Principles of Thermodynamics. (Du Bois.) 8vo, 5 00
Sinclair's Locomotive Engine Running and Management. 12mo, 2 00
Smart's Handbook of Engineering Laboratory Practice. 12mo, 2 50
Snow's Steam-boiler Practice. 8vo, 3 00
Spangler's Valve-gears. 8vo, 2 50
Notes on Thermodynamics. 12mo, 1 00
Spangler, Greene, and Marshall's Elements of Steam-engineering 8vo, 3 00
Thurston's Handy Tables. 8vo, 1 50
Manual of the Steam-engine. ....2 vols., 8vo, 10 00
Part I. History, Structure, and Theory. 8vo, 6 00
Part II. Design, Construction, and Operation. 8vo, 6 00
Handbook of Engine and Boiler Trials, and the Use of the Indicator and the Prony Brake. 8vo, 5 00
Stationary Steam-engines. 8vo, 2 50
Steam-boiler Explosions in Theory and in Practice 12mo, 1 50
Manual of Steam-boilers, their Designs, Construction, and Operation. 8vo, 5 00
Weisbach's Heat, Steam, and Steam-engines. (Du Bois.) 8vo, 5 00
Whitham's Steam-engine Design. 8vo, 5 00
Wilson's Treatise on Steam-boilers. (Flather.) 16mo, 2 50
Wood's Thermodynamics, Heat Motors, and Refrigerating Machines. 8vo, 4 00

MECHANICS AND MACHINERY.

Barr's Kinematics of Machinery. 8vo, 2 50
Bovey's Strength of Materials and Theory of Structures 8vo, 7 50
Chase's The Art of Pattern-making. 12mo, 2 50
Church's Mechanics of Engineering. 8vo, 6 00

Church's Notes and Examples in Mechanics..........................8vo, 2 00
Compton's First Lessons in Metal-working..........................12mo, 1 50
Compton and De Groodt's The Speed Lathe..........................12mo, 1 50
Cromwell's Treatise on Toothed Gearing..........................12mo, 1 50
Treatise on Belts and Pulleys..........................12mo, 1 50
Dana's Text-book of Elementary Mechanics for Colleges and Schools..12mo, 1 50
Dingey's Machinery Pattern Making..........................12mo, 2 00
Dredge's Record of the Transportation Exhibits Building of the World's Columbian Exposition of 1893..........................4to half morocco, 5 00
Du Bois's Elementary Principles of Mechanics:
Vol. I. Kinematics..........................8vo, 3 50
Vol. II. Statics..........................8vo, 4 00
Vol. III. Kinetics..........................8vo, 3 50
Mechanics of Engineering. Vol. I..........................Small 4to, 7 50
Vol. II..........................Small 4to, 10 00
Durley's Kinematics of Machines..........................8vo, 4 00
Fitzgerald's Boston Machinist..........................16mo, 1 00
Flather's Dynamometers, and the Measurement of Power..........................12mo, 3 00
Rope Driving..........................12mo, 2 00
Goss's Locomotive Sparks..........................8vo, 2 00
Hall's Car Lubrication..........................12mo, 1 00
Holly's Art of Saw Filing..........................18mo, 75
James's Kinematics of a Point and the Rational Mechanics of a Particle. Sm. 8vo, 2 00
* Johnson's (W. W.) Theoretical Mechanics..........................12mo, 3 00
Johnson's (L. J.) Statics by Graphic and Algebraic Methods..........................8vo, 2 00
Jones's Machine Design:
Part I. Kinematics of Machinery..........................8vo, 1 50
Part II. Form, Strength, and Proportions of Parts..........................8vo, 3 00
Kerr's Power and Power Transmission..........................8vo, 2 00
Lanza's Applied Mechanics..........................8vo, 7 50
Leonard's Machine Shop, Tools, and Methods..........................8vo, 4 00
*Lorenz's Modern Refrigerating Machinery. (Pope, Haven, and Dean.).8vo, 4 00
MacCord's Kinematics; or, Practical Mechanism..........................8vo, 5 00
Velocity Diagrams..........................8vo, 1 50
Maurer's Technical Mechanics..........................8vo, 4 00
Merriman's Mechanics of Materials..........................8vo, 5 00
* Elements of Mechanics..........................12mo, 1 00
* Michie's Elements of Analytical Mechanics..........................8vo, 4 00
Reagan's Locomotives: Simple, Compound, and Electric..........................12mo, 2 50
Reid's Course in Mechanical Drawing..........................8vo, 2 00
Text-book of Mechanical Drawing and Elementary Machine Design.8vo, 3 00
Richards's Compressed Air..........................12mo, 1 50
Robinson's Principles of Mechanism..........................8vo, 3 00
Ryan, Norris, and Hoxie's Electrical Machinery. Vol. I..........................8vo, 2 50
Schwamb and Merrill's Elements of Mechanism..........................8vo, 3 00
Sinclair's Locomotive-engine Running and Management..........................12mo, 2 00
Smith's (O.) Press-working of Metals..........................8vo, 3 00
Smith's (A. W.) Materials of Machines..........................12mo, 1 00
Spangler, Greene, and Marshall's Elements of Steam-engineering..........................8vo, 3 00
Thurston's Treatise on Friction and Lost Work in Machinery and Mill Work..........................8vo, 3 00
Animal as a Machine and Prime Motor, and the Laws of Energetics. 12mo, 1 00
Warren's Elements of Machine Construction and Drawing..........................8vo, 7 50
Weisbach's Kinematics and Power of Transmission. (Herrmann—Klein.).8vo, 5 00
Machinery of Transmission and Governors. (Herrmann—Klein.).8vo, 5 00
Wood's Elements of Analytical Mechanics..........................8vo, 3 00
Principles of Elementary Mechanics..........................12mo, 1 25
Turbines..........................8vo, 2 50
The World's Columbian Exposition of 1893..........................4to, 1 00

METALLURGY.

Egleston's Metallurgy of Silver, Gold, and Mercury:
Vol. I. Silver. 8vo, 7 50
Vol. II. Gold and Mercury..............................8vo, 7 50
** Iles's Lead-smelting. (Postage 9 cents additional.)...............12mo, 2 50
Keep's Cast Iron.......................................8vo, 2 50
Kunhardt's Practice of Ore Dressing in Europe......................8vo, 1 50
Le Chatelier's High-temperature Measurements. (Boudouard—Burgess.)12mo, 3 00
Metcalf's Steel. A Manual for Steel-users 12mo, 2 00
Smith's Materials of Machines..........................12mo, 1 00
Thurston's Materials of Engineering. In Three Parts.................8vo, 8 00
Part II. Iron and Steel.......................................8vo, 3 50
Part III. A Treatise on Brasses, Bronzes, and Other Alloys and their Constituents.......................................8vo, 2 50
Ulke's Modern Electrolytic Copper Refining.......................8vo, 3 00

MINERALOGY.

Barringer's Description of Minerals of Commercial Value. Oblong, morocco, 2 50
Boyd's Resources of Southwest Virginia. 8vo, 3 00
Map of Southwest Virignia......................Pocket-book form. 2 00
Brush's Manual of Determinative Mineralogy. (Penfield.).............8vo, 4 00
Chester's Catalogue of Minerals..........................8vo, paper, 1 00
Cloth, 1 25
Dictionary of the Names of Minerals..........................8vo, 3 50
Dana's System of Mineralogy.....................Large 8vo, half leather, 12 50
First Appendix to Dana's New "System of Mineralogy." .....Large 8vo, 1 00
Text-book of Mineralogy.......................................8vo, 4 00
Minerals and How to Study Them 12mo, 1 50
Catalogue of American Localities of Minerals...............Large 8vo, 1 00
Manual of Mineralogy and Petrography......................12mo, 2 00
Douglas's Untechnical Addresses on Technical Subjects.............12mo, 1 00
Eakle's Mineral Tables.......................................8vo, 1 25
Egleston's Catalogue of Minerals and Synonyms.......................8vo, 2 50
Hussak's The Determination of Rock-forming Minerals. (Smith.).Small 8vo, 2 00
Merrill's Non-metallic Minerals: Their Occurrence and Uses..........8vo, 4 00
* Penfield's Notes on Determinative Mineralogy and Record of Mineral Tests.
8vo. paper, 0 50
Rosenbusch's Microscopical Physiography of the Rock-making Minerals. (Iddings.).......................................8vo, 5 00
* Tillman's Text-book of Important Minerals and Rocks...............8vo, 2 00
Williams's Manual of Lithology.................................8vo, 3 00

MINING.

Beard's Ventilation of Mines.....................................12mo, 2 50
Boyd's Resources of Southwest Virginia............................8vo, 3 00
Map of Southwest Virginia.......................Pocket book form, 2 00
Douglas's Untechnical Addresses on Technical Subjects 12mo, 1 00
* Drinker's Tunneling, Explosive Compounds, and Rock Drills..4to, hf. mor.. 25 00
Eissler's Modern High Explosives.................................8vo, 4 00
Fowler's Sewage Works Analyses...........................12mo, 2 00
Goodyear's Coal-mines of the Western Coast of the United States.... .12mo, 2 50
Ihlseng's Manual of Mining.......................................8vo, 5 00
** Iles's Lead-smelting. (Postage 9c. additional.)...................12mo, 2 50
Kunhardt's Practice of Ore Dressing in Europe.......................8vo, 1 50
O'Driscoll's Notes on the Treatment of Gold Ores. 8vo, 2 00
* Walke's Lectures on Explosives.................................8vo, 4 00
Wilson's Cyanide Processes......................................12mo, 1 50
Chlorination Process..12mo, 1 50

Wilson's Hydraulic and Placer Mining. 12mo, 2 00
Treatise on Practical and Theoretical Mine Ventilation. 12mo, 1 25

SANITARY SCIENCE.

Bashore's Sanitation of a Country House. 12mo, 1 00
Folwell's Sewerage. (Designing, Construction, and Maintenance.). 8vo, 3 00
Water-supply Engineering. 8vo, 4 00
Fuertes's Water and Public Health. 12mo, 1 50
Water-filtration Works. 12mo, 2 50
Gerhard's Guide to Sanitary House-inspection 16mo, 1 00
Goodrich's Economic Disposal of Town's Refuse. . . . . Demy 8vo, 3 50
Hazen's Filtration of Public Water-supplies. 8vo, 3 00
Leach's The Inspection and Analysis of Food with Special Reference to State Control. 8vo, 7 50
Mason's Water-supply. (Considered principally from a Sanitary Standpoint) 8vo, 4 00
Examination of Water. (Chemical and Bacteriological.). 12mo, 1 25
Merriman's Elements of Sanitary Engineering. 8vo, 2 00
Ogden's Sewer Design. 12mo, 2 00
Prescott and Winslow's Elements of Water Bacteriology, with Special Reference to Sanitary Water Analysis. 12mo, 1 25
* Price's Handbook on Sanitation. 12mo, 1 50
Richards's Cost of Food. A Study in Dietaries. 12mo, 1 00
Cost of Living as Modified by Sanitary Science. 12mo, 1 00
Richards and Woodman's Air, Water, and Food from a Sanitary Standpoint. 8vo, 2 00
* Richards and Williams's The Dietary Computer. 8vo, 1 50
Rideal's Sewage and Bacterial Purification of Sewage. 8vo, 3 50
Turneaure and Russell's Public Water-supplies. 8vo, 5 00
Von Behring's Suppression of Tuberculosis. (Bolduan.) 12mo, 1 00
Whipple's Microscopy of Drinking-water. 8vo, 3 50
Woodhull's Notes on Military Hygiene. 16mo, 1 50

MISCELLANEOUS.

De Fursac's Manual of Psychiatry. (Rosanoff and Collins.). . . . Large 12mo, 2 50
Emmons's Geological Guide-book of the Rocky Mountain Excursion of the International Congress of Geologists. . . . . Large 8vo, 1 50
Ferrel's Popular Treatise on the Winds. 8vo. 4 00
Haines's American Railway Management. 12mo, 2 50
Mott's Composition, Digestibility, and Nutritive Value of Food. Mounted chart, 1 25
Fallacy of the Present Theory of Sound. 16mo, 1 00
Ricketts's History of Rensselaer Polytechnic Institute, 1824–1894. . Small 8vo, 3 00
Rostoski's Serum Diagnosis. (Bolduan.). 12mo, 1 00
Rotherham's Emphasized New Testament. . . . . Large 8vo, 2 00
Steel's Treatise on the Diseases of the Dog. 8vo, 3 50
Totten's Important Question in Metrology. 8vo, 2 50
The World's Columbian Exposition of 1893 . . . . 4to, 1 00
Von Behring's Suppression of Tuberculosis. (Bolduan.). 12mo, 1 00
Winslow's Elements of Applied Microscopy 12mo, 1 50
Worcester and Atkinson. Small Hospitals, Establishment and Maintenance; Suggestions for Hospital Architecture: Plans for Small Hospital. 12mo, 1 25

HEBREW AND CHALDEE TEXT-BOOKS.

Green's Elementary Hebrew Grammar. 12mo, 1 25
Hebrew Chrestomathy. 8vo, 2 00
Gesenius's Hebrew and Chaldee Lexicon to the Old Testament Scriptures. (Tregelles.). . . . . Small 4to, half morocco, 5 00
Letteris's Hebrew Bible. 8vo, 2 25

..12mo,
..12mo,

.12mo,
..8vo,
..8vo,
12mo,
12mo,
6mo,
8vo, 3
8vo, 3
tate
vo, 7
vo, 4
o, 1
o, 2 00
o, 2 00
r-
, 1 25
1 50
, 1 00
, 1 0
, 2 00
, 1 5
3 5
, 5 0
1 0
3 5
1 5

2 5

1
4
2
1
1
3
1

Jeken
750 8

220
150